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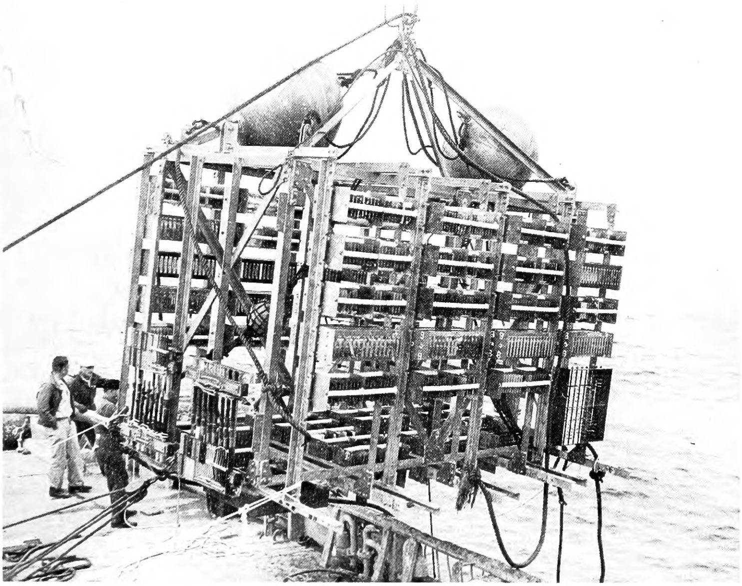

CORROSION OF METALS AND ALLOYS IN THE DEEP OCEAN

by F. M. Reinhart

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Between 1960 and 1970, about 20,000 specimens of 475 alloys were exposed in the seawater in the Pacific Ocean in order to conduct a program on the effects of deep-ocean environments on materials. The test specimens included steels, cast irons, stainless steels, copper, nickel, aluminum, titanium, miscellaneous alloys, and wire ropes. They were exposed at the surface and at nominal depths of 2,500 and 6,000 feet for periods of time varying

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20. Continued

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Between 1960 and 1970, about 20,000 specimens of 475 alloys were exposed in the seawater in the Pacific Ocean in order to conduct a program on the effects of deep-ocean environments on materials. The test specimens included steels, cast irons, stainless steels, copper, nickel, aluminum, titanium, miscellaneous alloys, and wire ropes. They were exposed at the surface and at nominal depths of 2,500 and 6,000 feet for periods of time varying from 123 to 1,064 days. The results of their corrosion behavior have been issued in 15 Civil Engineering Laboratory reports; other Navy Department reports from Naval Air Development Center, Naval Ship Research and Development Center (Annapolis) and Naval Underwater Ordnance Center; and from nongovernment participants. Very little of this information is available in the open literature. Therefore, this information has been compiled, analyzed, and evaluated in this report.

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SECTION 1

INTRODUCTION

Between 1962 and 1970 the Civil Engineering Laboratory, Naval Construction Battalion Center, Port Hueneme, California, exposed approximately 20,000 specimens of about 475 different alloys in the Pacific Ocean. These specimens were exposed at the surface and at nominal depths of 2,500 and 6,000 feet for periods of time varying from 123 to 1,064 days.

The purpose of these exposures was to provide the Naval Facilities Engineering Command (NAVFAC) with information on the deterioration of materials in deep-ocean environments. Such information was needed to improve techniques, to develop new techniques pertaining to naval material, and to support the increasing interest in the deep ocean as an operating environment.

The Naval Facilities Engineering Command is charged with the responsibility for the construction and maintenance of all fixed Naval facilities; hence, the construction and maintenance of Naval structures at depths in the oceans are but one facet of its overall responsibility. Fundamental to the design, construction, maintenance, and operation of structures and their related facilities is information on the deterioration of materials in a particular environment. Since there was very little published information on the behavior of construction materials in deep-ocean environments, this program was initiated in 1960 to obtain such information.

In-situ testing was chosen because it is not possible to duplicate all the variables and the changes in these variables that prevail in any one environment or location. A test site was considered suitable if the circulation (currents), sedimentation, and bottom conditions were representative of open ocean conditions: (1) the bottom should be reasonably flat, (2) the site should be open and not located in an area of restricted circulation, such as a silled basin, (3) the site should be reasonably close to Port Hueneme for ship operations, and (4) the site should be within the operating range of the more precise navigating and locating techniques.

A Pacific Ocean site meeting these requirements was selected at a nominal depth of 6,000 feet. The ocean bottom at this site is relatively flat in a broad submarine valley southwest of San Miguel Island, California; it is readily accessible to the Civil Engineering Laboratory; and it is subject to the effects of ocean currents. This site, designated Test Site I, is approximately 81 nautical miles southwest of Port Hueneme, latitude 33°44′N, longitude 120°45′W.

Oceanographic data collected between 1961 and 1963 [1,2] show the presence of an oxygen minimum zone at depths between 2,000 and 3,000 feet. This minimum oxygen zone was present at all sites investigated when the ocean floor was at depths varying between 2,000 and 13,000 feet.

It is well known that the corrosion rates of many materials (e.g., steels) are affected by the concentration of oxygen in the environment. Because of this, it was decided to establish a second test site, Test Site II, in this minimum oxygen concentration zone where, it was thought, much pertinent information could be obtained. Test Site II (nominal depth of 2,500 feet) is 75 nautical miles west of Port Hueneme, latitude 34°06′N, longitude 120°42′W.

The oceanographic investigations by the Civil Engineering Laboratory also disclosed that the ocean floor at these sites is rather firm and was characterized as sandy, green cohesive mud (partially glauconite) with some rocks. Biological cultures of these bottom sediments showed the presence of sulfate-reducing bacteria in at least the first 6 inches of sediment.

In order to determine the differences between the corrosiveness of seawater at depths and at the surface in the Pacific Ocean, it is desirable to compare deep-ocean corrosion data with surface immersion data. Since surface data from the Pacific Ocean in the vicinity of Port Hueneme were not available in the literature for most of the alloys exposed at depths in the Pacific Ocean, it was decided to establish a surface exposure site to obtain this information. Therefore, a third site, Test Site V, was established at the

Naval Pacific Missile Range, Point Mugu, California, latitude 34°06'N, longitude 119°07'W. Test Site V is about 10 miles east of Port Hueneme.

The specific geographical locations of the test sites and the average characteristics of the seawater 10 feet above the ocean floor at these sites are given in Table 1. Their positions relative to the California coast are shown in Figure 1. The variation of the temperature, pH, salinity and oxygen content of the seawater with depth at the STU sites is shown in Figure 2.

Other naval activities were invited to participate in this program and, if possible, to contribute to the funding. From 1962 to 1966 the Naval Air Systems Command supplied funds for partial support of the program. Navy contractors and other companies also participated in this program. The participants are listed in Table 2 as well as those who evaluated the materials and whether or not the evaluators, other than CEL, supplied CEL with the results of their evaluations.

This report presents the performance data obtained by CEL and other participants from the seawater exposures at the sites given in Table 1. The performance of the various materials as supported by this data is also discussed.

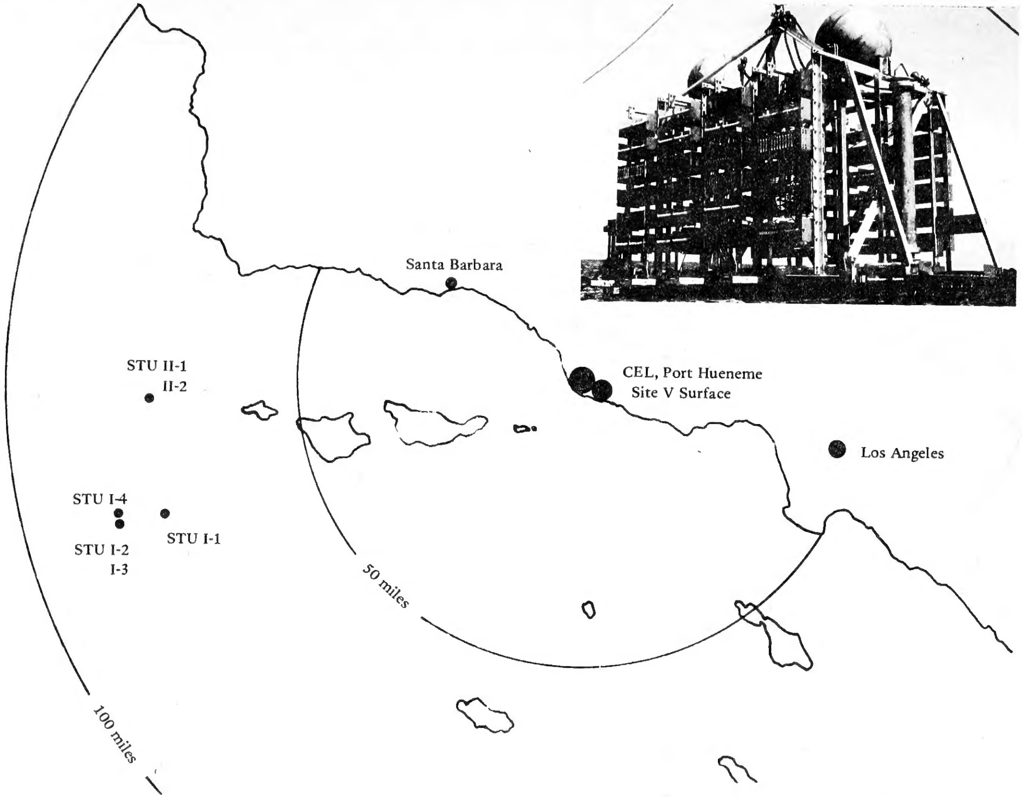

Figure 1. STU sites off the Pacific Coast; STU structure in inset.

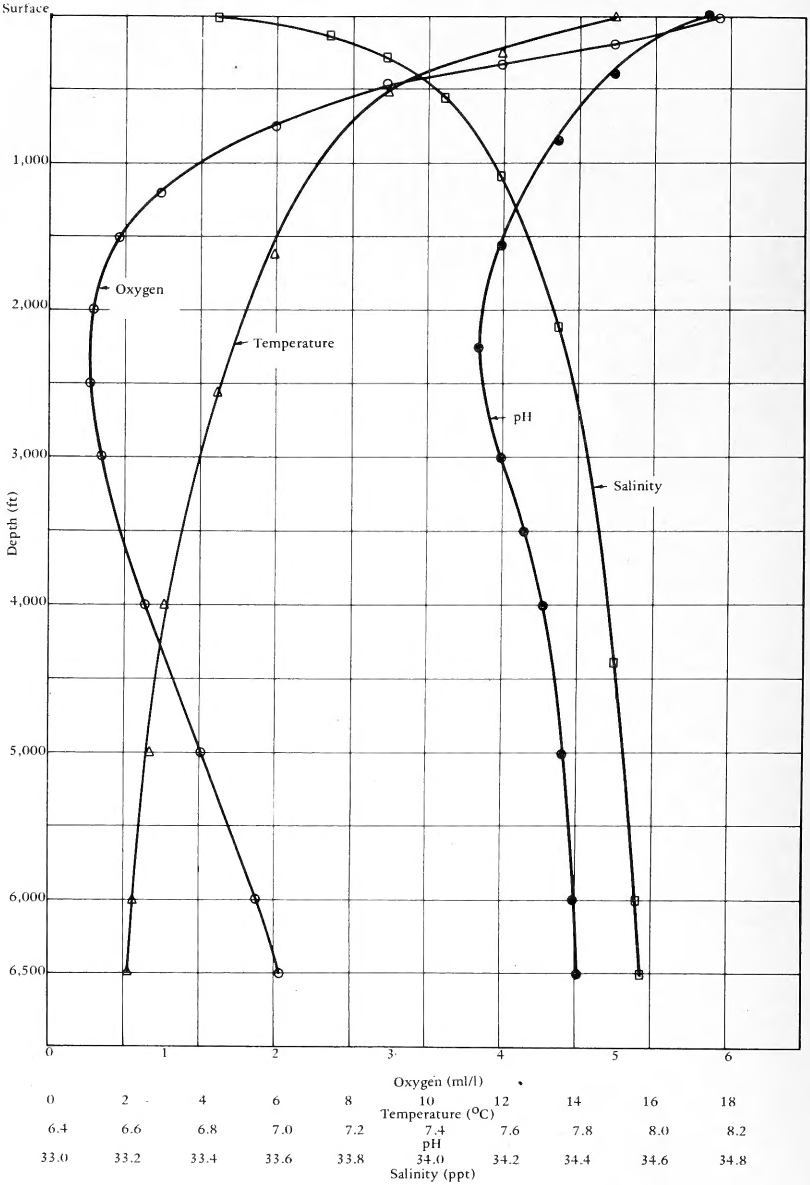

Figure 2. Variation of environment with depth at STU sites.

Table 1. Exposure Site Locations and Seawater Characteristics

Site No.	Latitude N	Longitude W	Depth (ft)	Exposure (day)	Temperature (^oC)	Oxygen (ml/l)	Salinity (ppt)	pH	Average Current (knot)
I-1	33°46'	120°37'	5,300	1,064	2.6	1.2	34.51	7.5	0.03
I-2	33°44'	120°45'	5,640	751	2.3	1.3	34.51	7.6	0.03
I-3	33°44'	120°45'	5,640	123	2.3	1.3	34.51	7.6	0.03
I-4	33°46'	120°46'	6,780	403	2.2	1.6	34.40	7.7	0.03
I-5	33°51'	120°35'	5,900	189	2.3	1.6	34.6	7.4	0.03
II-1	34°06'	120°42'	2,340	197	5.0	0.4	34.36	7.5	0.06
II-2	34°06'	120°42'	2,370	402	5.0	0.4	34.36	7.5	0.06
V	34°06'	119°07'	5	181-763	12-19	3.9-6.6	33.51	8.1	variable

Table 2. Participants in Test Program

Name	Materials Evaluated By	Report Submitted to CEL
Aerojet-General Corp.	AGC	no
Aluminum Company of America	CEL	–
Allegheny Ludlum Steel Corp.	CEL	–
American Chain and Cable Co.	CEL	–
American Steel and Wire Div., U.S.S.	CEL	–
Anaconda American Brass Co.	CEL	–
Anaconda Wire and Cable Co.	AWCC	yes
Armco Steel Corp.	CEL	–
Baldt Anchor Chain and Forge Div., Boston Metals Co.	CEL	–
Bell Telephone Laboratories	BTL	yes
Bethlehem Steel Co.	CEL	–
Boeing Co.	Boeing	yes
Brush Beryllium Co.	CEL	–
Carpenter Steel Co.	CEL	–
E. I. Dupont Co.	CEL	–
Elgiloy Co.	CEL	–
Fansteel Metallurgical Corp.	CEL	–
Goodyear Aerospace Corp.	GAC	yes
Haynes Stellite Div., Cabot Corp.	CEL	–
Hooker Chemical Corp.	CEL	–

Continued

Table 2. Continued.

Name	Materials Evaluated By	Report Submitted to CEL
International Nickel Co., Inc.	INCO/CEL	yes/–
Joseph T. Reyerson & Son	CEL	–
Kaiser Aluminum and Chemical Corp.	CEL	–
Kawecki Berylco Industries	CEL	–
Lukens Steel Co.	CEL	–
Menasco Manufacturing Co.	MMC	no
Metco Inc.	CEL	–
Military Consultant Service	CEL	–
Minnesota Mining and Manufacturing Co.	3M	–
Mobay Chemical Co.	CEL	–
Naval Air Development Center	NADC	yes
Naval Air Systems Command	NASC	yes
Naval Electronics Laboratory	NEL	no
NAVFAC, Code 042	CEL	–
Naval Ordnance Test Station	NOTS	no
Naval Pacific Missile Range	CEL	–
Naval Ship Research and Development Center, Annapolis Div.	NSRDC(A)[a]	yes
Naval Underwater Ordnance Station	NUOS	no
Owens Corning Fiberglass Corp.	CEL	–
Reactive Metals Inc.	CEL	–
Republic Steel Corp.	CEL	–
Reynolds Metals Co.	RMC	yes
Scripps Institution of Oceanography	CEL	–
Shell Development Co.	Shell	yes
Standard Pressed Steel Co.	CEL	–
Taylor Fibre Co.	CEL	–
Texas Instruments, Inc.	CEL	–
Titanium Metals Corporation of America	CEL	–
TRW Space Technology Laboratories	TRW	yes
Tube Turns Plastic Co.	CEL	–
U.S. Rubber Co.	CEL	–
U.S. Steel Corp.	USS/CEL	yes/–
Valley Bolt Co.	CEL	–

[a] Formerly Marine Engineering Laboratory (MEL), Annapolis, Maryland.

SECTION 2

STEEL AND CAST IRONS

The data discussed in this section were obtained from the reports given in References 3 through 19. The chemical compositions of the alloys are given in Table 3; their surface conditions and heat treatments, if any, are given in Table 4.

The corrosion rates and types of corrosion of all the alloys are given in Table 5. Inorganic coatings were applied to some steels to evaluate their protective qualities. These coatings and their conditions are given in Table 6. Steels that were exposed in a stressed condition to determine their susceptibility to stress corrosion cracking are given in Table 7.

The effects of corrosion on the mechanical properties of many of the alloys were determined after various periods of exposure; these results are given in Table 8.

Water near the surface in the open sea is quite uniform in its composition throughout the oceans [20]; therefore, the corrosion rates of steels exposed under similar conditions in clean seawater should be comparable. The results of many investigations on the corrosion of structural steels in surface seawater at many locations throughout the world show that after a short period of exposure the corrosion rates are constant and amount to between 3 and 5 mils per year [21,22]. Factors which can cause differences in corrosion rates outside these limits are variations in marine fouling, contamination of the seawater near the shorelines, variations in seawater velocity, and differences in the surface water temperature.

2.1. IRONS AND STEELS

The corrosion rates of the irons; mild steels; high-strength low-alloy steels; high-strength steels; other alloy steels; and nickel alloy steels are given in Table 5. Analysis of the corrosion rates of these alloys shows that for all practical purposes their corrosion rates were comparable for any one duration of exposure at any one depth or at the surface. Therefore, these data were treated statistically to obtain one median value for each time of exposure and each depth. These average data values were used to plot curves to show the general corrosion behavior to be expected from these alloys with regard to duration of exposure, depth in the ocean, and concentration of oxygen in seawater.

2.1.1. Duration of Exposure

The effects of the duration of exposure on the corrosion of steels in seawater at the surface and at depth are shown in Figure 3. The corrosion rates of the steels exposed in seawater at nominal depths of 2,500 and 6,000 feet in the Pacific Ocean decreased with increasing duration of exposure and were consistently lower than the surface corrosion rates by a factor of approximately 3. The corrosion rates at the 2,500-foot depth also were lower than those at the 6,000-foot depth. The corrosion rates decreased asymptotically with increasing duration of exposure both at the surface and at the 6,000-foot depth.

The performance of the steels when partially embedded in the bottom sediments at the 2,500- and 6,000-foot depths is shown in Figure 4. Here, also, the average corrosion rates of the steels at the 6,000-foot depth decreased asymptotically with increasing duration of exposure. During the initial exposures the steels corroded at faster rates in seawater than in the bottom sediments at the 6,000-foot depth, but after approximately 2 years of exposure, their average corrosion rates were approximately the same as shown by comparing the curves in Figures 3 and 4. Here, also, the average corrosion rates at the 2,500-foot depth were lower than at the 6,000-foot depth, but they increased with increasing duration of exposure.

2.1.2. Depth

The effect of depth of exposure in seawater on the average corrosion rates of the steels is shown in Figure 5. The variation of the concentration of oxygen in seawater with depth is also shown in Figure 5 for comparison purposes. The shape of the curve for steels shows that corrosion of steels is not affected by depth (pressure), at least to a depth of 6,000 feet (2,700 psi) for a period of 1 year of exposure. The shape of this curve is practically identical to that of the oxygen concentration curve. The identical shape of these curves indicate that the concentration of oxygen in seawater exerts a major influence on the corrosion of steels in this environment.

2.1.3. Concentration of Oxygen

The effect of the variation in the concentration of oxygen in seawater on the corrosion of steels after 1 year of exposure is shown in Figure 6. The curve for the average corrosion rates of the steels after 1 year of exposure versus the concentration of oxygen is a straight line. This indicates that the corrosion of steels in seawater is proportional to the concentration of oxygen.

2.1.4. Nickel

The effect of the variation of the concentration of nickel on the corrosion of steels is shown in Figure 7. Variations of from 1.5 to 9% in the nickel content were ineffectual with respect to the corrosion of steel both at the surface and at depth. However, the corrosion rates in surface exposures were higher than at depth by about a factor of 7.

2.1.5. Type of Corrosion

All the steel, except AISI Type 502, in general, corroded uniformly except for some slight pitting in surface seawater which was caused by fouling. The corrosion rates of AISI Type 502 steel (5% Cr-0.5% Mo) were erratic and higher than those of the other steels. This behavior is attributed to the broad, shallow pitting and the severe crevice corrosion caused by the chromium content of the steel.

2.1.6. Metallic Coatings

Zinc, aluminum, sprayed aluminum, titanium-cadmium, cadmium, copper, and nickel-coated steel specimens were exposed at depth.

A 1 oz/sq ft of zinc on galvanized steel sheet exposed at a depth of 2,500 feet protected the steel for from 3 to 4 months in the seawater and for about 7 months when partially embedded in the bottom sediments.

A 1 oz/sq ft of aluminum on aluminized steel sheet exposed at a depth of 2,500 feet protected the steel for at least 13 months in the seawater and when partially embedded in the bottom sediments.

A 6-mil-thick hot-sprayed aluminum coating over steel, which had been subsequently primed and sprayed with two coats of clear vinyl sealer, protected the underlying steel from corroding for 1,064 days at the 6,000-foot depth. After removal from exposure the aluminum coating was dark gray and speckled with pin-point size areas of white corrosion products. Since no red rust was present, it is evident that this coating would provide added protection to the steel for an additional period of time, possibly another 3 years.

A titamium-cadmium coating on AISI 4130 steel was completely sacrificed, and the underlying steel was covered with a layer of red rust after 402 days of exposure at a depth of 2,500 feet. Such a coating would not provide satisfactory protection for seawater applications.

An electrolytically applied cadmium coating on steels, both stressed and unstressed, did not provide adequate protection for 1 year of exposure at depths of 2,500 and 6,000 feet.

Electrolytically applied copper and nickel coatings on steels, both stressed and unstressed, failed within 6 months after exposure at the 2,500-foot depth and caused galvanic corrosion of the underlying steels.

2.1.7. Inorganic Coatings

A few steels were coated with selected paint coatings to determine their performance at depths in the Pacific Ocean. Table 6 shows the results of this test.

The multicoat epoxy systems exhibited, in general, satisfactory performance, while the multicoat polyurethane system behaved erratically, varying from cracked and blistered paint to no paint failures. The single-coat, zinc-rich primer coating did not afford satisfactory protection for a period of 6 months at a depth of 6,000 feet.

2.1.8. Cathodic Protection

Sacrificial zinc anodes were attached to AISI Type 1015 steel to determine its effectiveness in providing cathodic protection to a more noble material at these depths.

The sacrificial zinc anodes were effective in reducing the corrosion of the AISI Type 1015 steel. They provided nearly complete protection for 123 days, 50% protection during 751 days of exposure, and 30% during 1,064 days of exposure.

2.1.9. Galvanic Corrosion

A few galvanic couples (dissimilar metals) of AISI Type 4130 and AISI Type 4140, 1 x 7-inch steel strips with 1-inch-square pieces of 6061 and 7075-T6 aluminum alloys, AZ31B magnesium alloy, aluminum bronze alloy, titanium metal, and AISI Type 308 stainless steel attached to them were exposed at depths of 2,500 and 6,000 feet for 400 days to determine their compatibilities.

After 400 days of exposure at a depth of 6,000 feet aluminum alloy 6061 attached to AISI Type 4130 steel was moderately corroded with practically no corrosion of the steel; the aluminum alloy 7075-T6 was severely corroded under the same conditions. Magnesium alloy AZ31B was nearly completely sacrificed when attached to AISI Type 4130 steel, but the steel was also corroded because of the insulating layer of magnesium alloy corrosion products which accumulated at the faying surfaces of the two alloys. AISI Type 4130 steel was extensively corroded when in contact with the aluminum bronze.

After 400 days of exposure at a depth of 2,500 feet, AISI Type 4340 steel was rusted considerably from being in contact with titanium metal or AISI Type 308 stainless steel.

2.1.10. Stress Corrosion

Some of the steels were exposed in a stressed condition at stresses equivalent to from 30 to 75% of their respective yield strengths. The steels, stresses, depths, days of exposure, and their susceptibility to stress corrosion cracking are given in Table 7.

One-half-inch AISI Type 4140 steel bolts, heat-treated to about 175,000 psi tensile strength, failed during 400 days of exposure – one in the bottom sediment and two in the seawater at the 2,500-foot depth. Whether these failures were due to stress corrosion or hydrogen embrittlement is not certain. Bolts of such hardness should not be used in deep-sea applications.

One nickel-plated specimen of AISI Type 4130 steel, stressed at 127,000 psi, failed during 197 days of exposure at a depth of 2,500 feet. Since no unplated specimens failed, it is possible that the failure was caused by the nickel plating. Hydrogen absorbed into the metal during the plating process could have caused hydrogen enbrittlement, which in turn caused the failure.

Some 18 Ni maraging specimens failed by stress corrosion when stressed at various levels, under different conditions, for different periods of time at different depths. These results indicate that the stress corrosion behavior of this steel is unpredictable and unreliable when used at high stress levels (above about 150,000 psi yield strength) for seawater applications.

The other steels were not susceptible to stress corrosion.

2.1.11. Mechanical Properties

The percent changes in the mechanical properties of the steels resulting from corrosion are given in Table 8.

The percent elongation of HSLA No. 5 in thicknesses of 1/4 inch and 1/8 inch was decreased by 77 and 82%, respectively, after 400 days of exposure at the 2,500-foot depth.

The mechanical properties of AISI Type 4130 steel, bare, cadmium, copper, or nickel-plated were affected after 400 days of exposure at the 2,500-and 6,000-foot depths. Cadmium, copper, or nickel plating on AISI Type 4340 steel also caused decreases in the mechanical properties of the steel after exposure for 400 days at the 2,500-foot depth.

Because of pitting corrosion the elongation of AISI Type 502 (5% Cr) steel was decreased from 13 to 38% during all exposures at both depths, except for 197 days at the 2,500-foot depth.

The mechanical properties of the 18 Ni maraging steels were, in general, adversely affected by exposure at depth in the Pacific Ocean.

2.1.12. Corrosion Products

The corrosion products from some of the steels were analyzed by X-ray diffraction, spectrographic analysis, quantitative chemical analysis, and infrared spectrophotometry. The constituents found were:

Alpha iron oxide – $Fe_2O_3 \cdot H_2O$

Iron hydroxide – $F3(OH)_2$

Beta iron (III) oxide hydroxide – FeOOH

Iron oxide hydrate – $Fe_2O_3 \cdot H_2O$

Significant amounts of chloride, sulfate, and phosphate ions.

2.2. ANCHOR CHAINS

Two types of 3/4-inch-diameter anchor chains, Dilok and welded stud link, were exposed as shown in Table 9. The chain links were covered with layers of loose, flaky rust which varied from thin to thick as the time of exposure increased. Exposure for as long as 751 days did not decrease the breaking loads of the chains as shown in Table 9. In most cases there was rust in the bottoms of the sockets of the Dilok chain, indicating that seawater had penetrated the sockets. This could be a source of additional corrosion and early failure of this type of chain.

2.3. CAST IRONS

The corrosion rates of the cast irons are given in Table 5. Analysis of this data shows that for all practical purposes the corrosion rates of the alloy cast irons (nickel, nickel-chromium No. 1 and 2, and ductile irons No. 1 and 2) are comparable. This is also true of the austenitic cast irons. These average data values were used to plot curves to show the general corrosion behavior to be expected from these alloys with regard to duration of exposure, depth in the ocean, and concentration of oxygen in seawater.

2.3.1. Duration of Exposure

The effects of duration of exposure on the corrosion of cast irons in seawater at the surface and at depth are shown in Figure 3.

There was no measurable corrosion of the high silicon and the high silicon-molybdenum cast irons in seawater, either at the surface or at depth.

In all three environments (surface, 2,500-, and 6,000-foot depths), the corrosion rates decreased with increasing duration of exposure and were consistently lower at depth than at the surface. The corrosion rates at the 2,500-foot depth were lower than those at the 6,000-foot depth. At the surface and at the 6,000-foot depth the corrosion rates decreased asymptotically with increasing duration of exposure. At the 6,000-foot depth the corrosion rates of the austenitic cast irons, for the first 400 days of exposure, were lower than those of the gray and alloy cast irons, but they were comparable after longer periods of exposure, about 1 mpy. However, at the 2,500-foot depth, the corrosion rates of the austenitic cast irons were lower than those of the alloy and gray cast irons for exposures of up to 400 days.

The corrosion of the cast irons when partially embedded in the bottom sediments is shown in Figure 4. Here again, there was no measurable corrosion of the high silicon and high silicon-molybdenum cast irons in the bottom sediment at either depth.

The other cast irons behaved essentially the same as in the seawater except that the alloy cast irons initially corroded at slower rates than in the seawater at the 6,000-foot depth. After 2 years of exposure at the 6,000-foot depth in both the seawater and the bottom sediments, all the steels and cast irons corroded at essentially the same rate.

In the sediments at the 2,500-foot depth the corrosion rates of the austenitic cast irons tended to increase very slightly with increasing duration of exposure, while those of the alloy cast irons increased considerably.

2.3.2. Depth

The effect of depth of exposure in seawater on the average corrosion rates of the alloy and austenitic cast irons as well as those of the gray and high silicon cast irons is shown in Figure 5. The variation of the concentration of oxygen in seawater with depth is also shown in Figure 5 for comparison purposes. The shapes of the curves for the cast irons show that the corrosion of the cast irons is not directly affected by depth (pressure), at least to a depth of 6,000 feet for a period of 1 year.

2.3.3. Concentration of Oxygen

The effect of the variation in the concentration of oxygen in seawater on the corrosion of cast irons after 1 year of exposure is shown in Figure 6. The curves for the average corrosion rates of the gray, alloy, and austenitic cast irons versus the concentration of oxygen are essentially straight lines. This indicates that the corrosion of the cast irons in seawater is proportional to the concentration of oxygen. However, the different slopes of the curves indicate different degrees of influence, the influence being greatest on the alloy cast irons and least on the gray cast irons. Oxygen exerted no influence on the corrosion of high silicon or high silicon-molybdenum cast irons.

2.3.4. Type of Corrosion

All the cast irons corroded uniformly both in the seawater and in the bottom sediments. The high silicon and high silicon-molybdenum cast irons were uncorroded in any of the environments.

2.3.5. Mechanical Properties

The percent changes in the mechanical properties of the cast irons due to exposure in seawater are given in Table 8. The mechanical properties of the Type 4 austenitic cast iron were not affected by exposure either at the surface or at the 2,500-foot depth. However, the mechanical properties of the D-2C austenitic cast iron were significantly lowered. About 80% of the surfaces of fracture of the D-2C specimens were black in contrast to the gray surfaces of fracture of unexposed specimens. Metallographic examinations of polished cross sections of the D-2C alloy adjacent to the surfaces of fracture showed that the alloy had been attacked by selective interdendritic corrosion. This selective corrosion was the cause of the decrease in mechanical properties of the alloy.

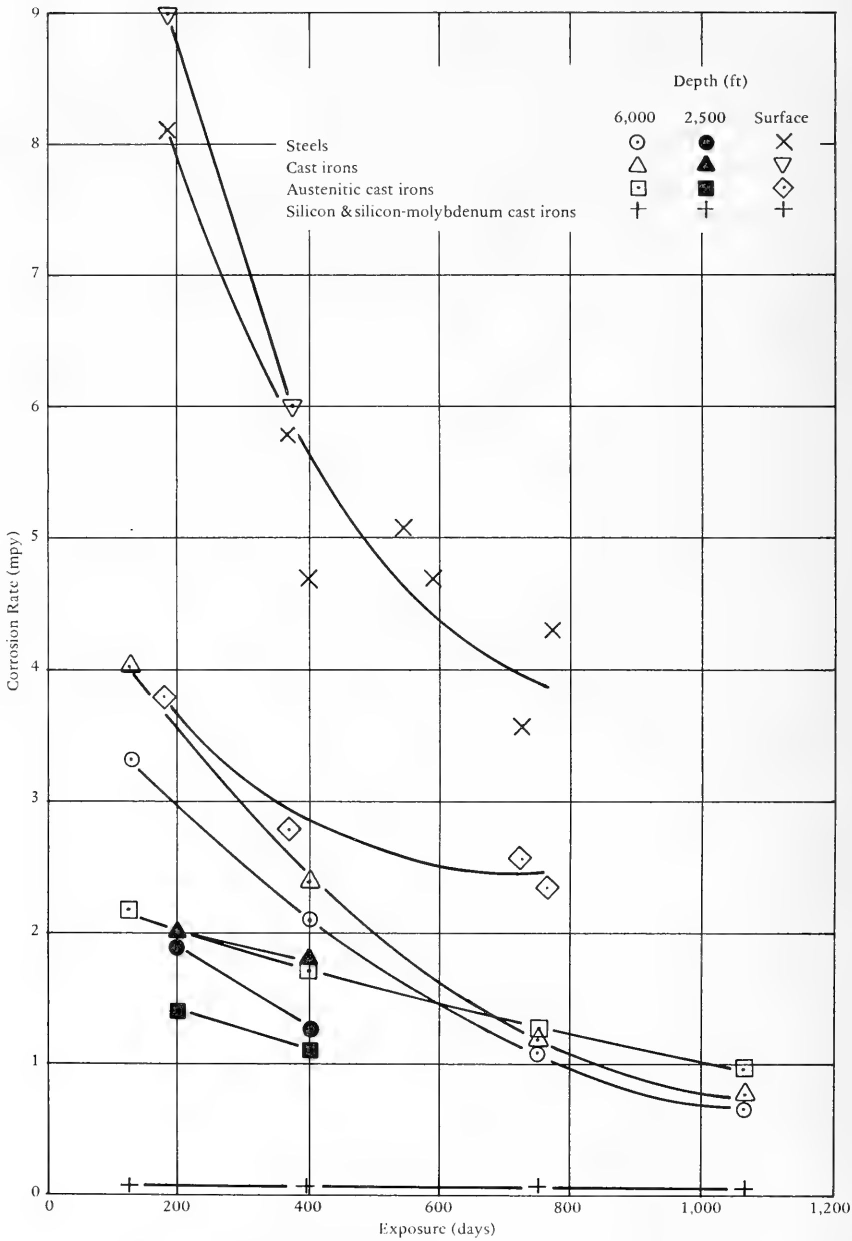

Figure 3. Effect of duration of exposure on corrosion of steels and cast irons.

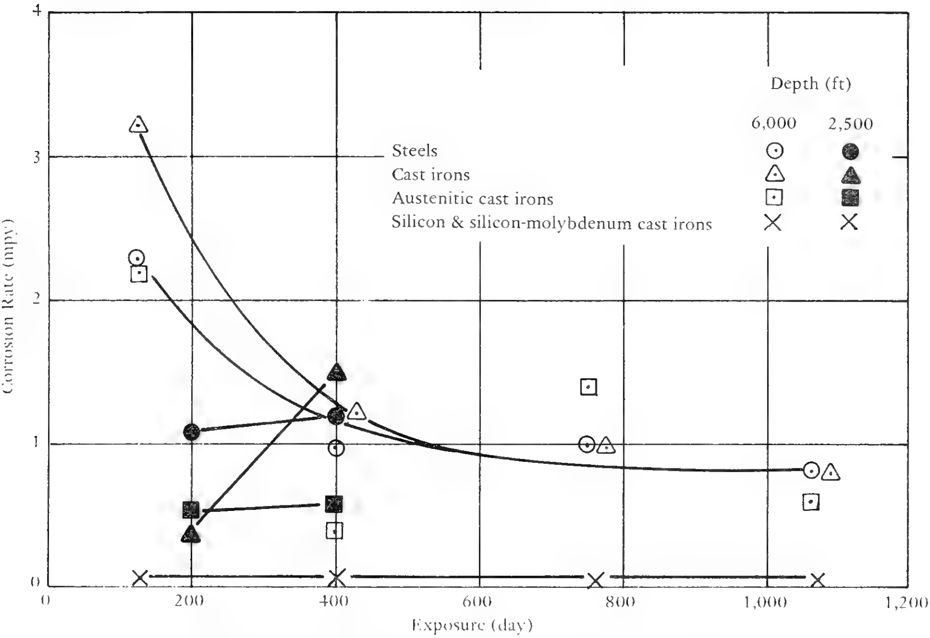

Figure 4. Effect of duration of exposure on corrosion of steels and cast irons in bottom sediments.

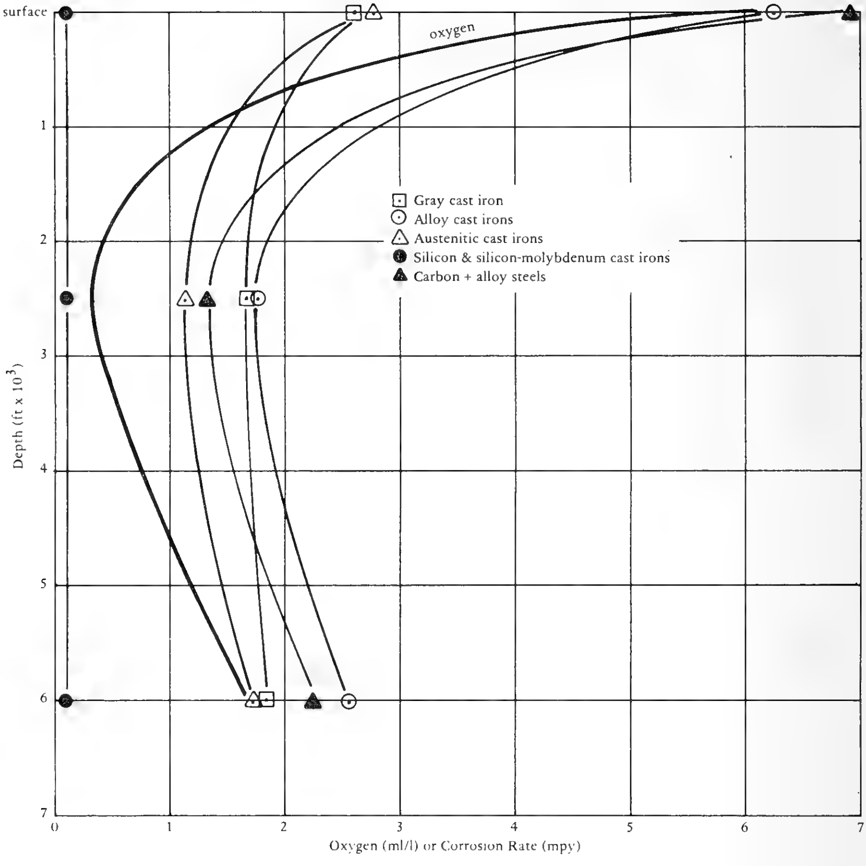

Figure 5. Effect of depth on the corrosion of steels and cast irons after 1 year of exposure in seawater.

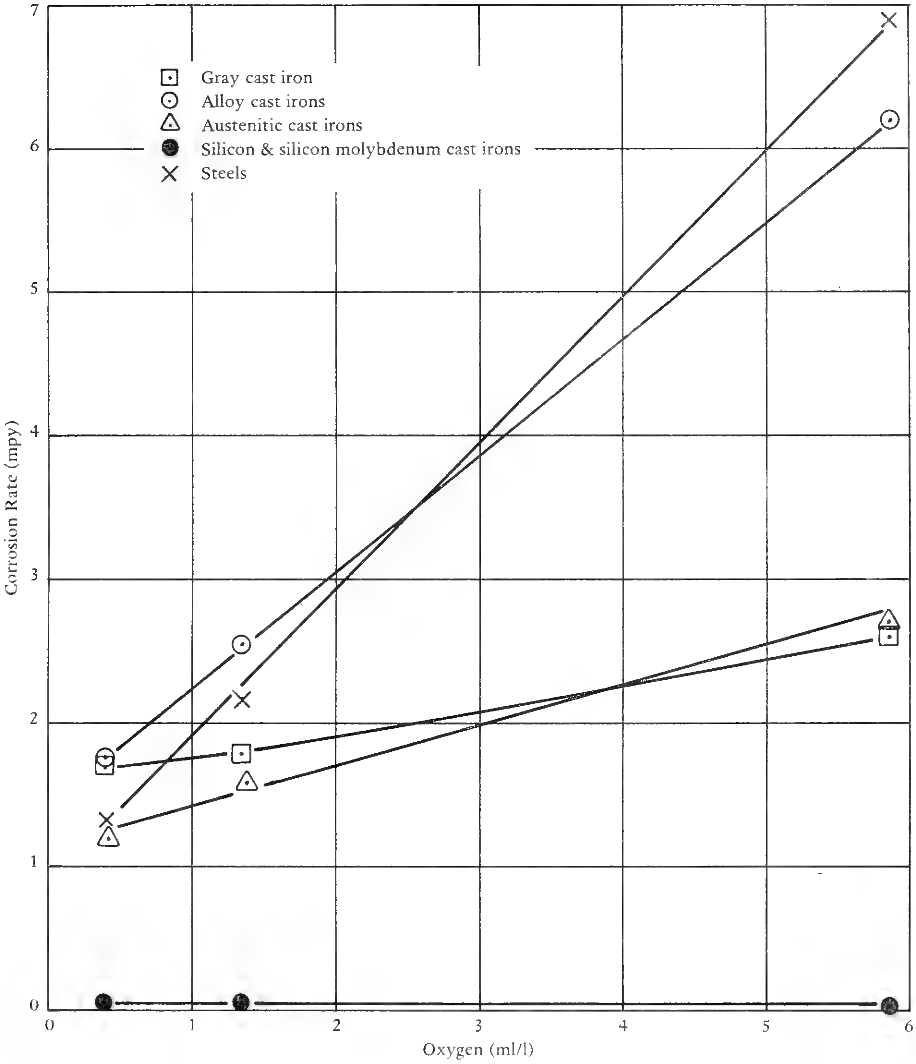

Figure 6. Effect of concentration of oxygen in seawater on the corrosion of steels and cast irons after 1 year of exposure.

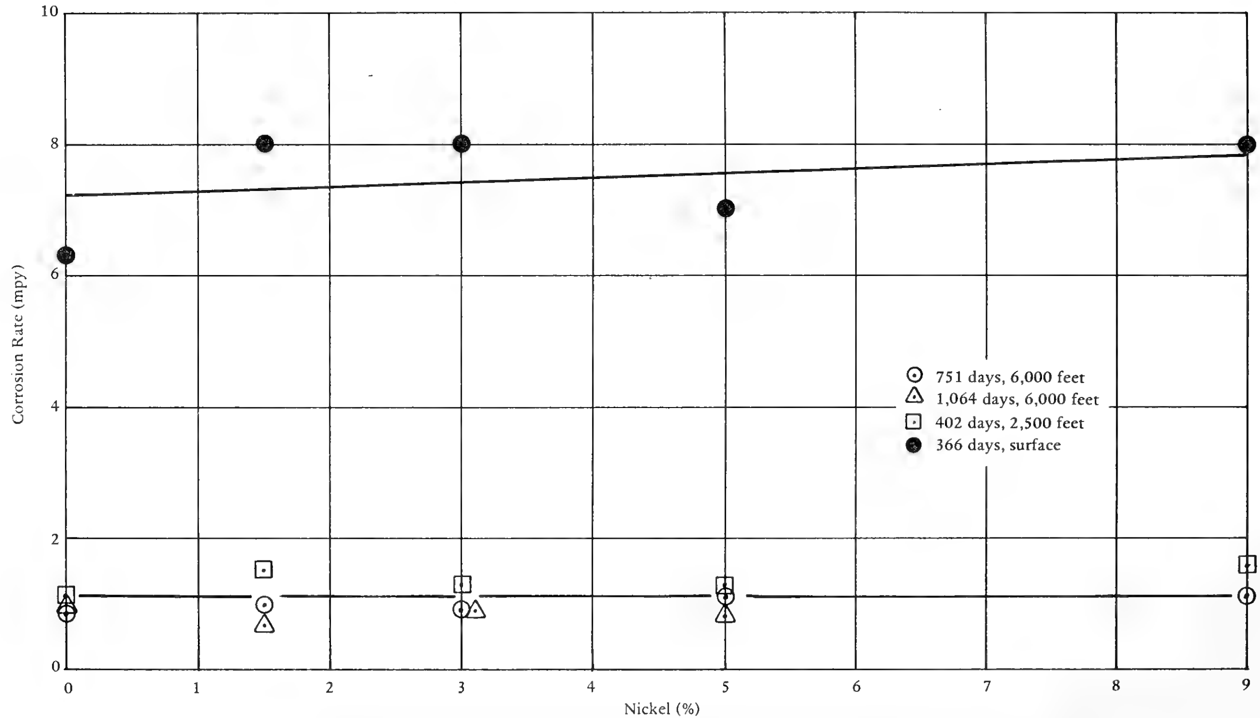

Figure 7. Effect of nickel on the corrosion of steel in seawater.

Table 3. Chemical Composition of Steels and Irons, Percent by Weight

Alloy	C	Mn	P	S	Si	Ni	Cr	Mo	Cu	Co	Other	Source[a]
Wrought iron	0.02	0.06	0.13	0.01	0.13	–	–	–	–	–	2.5 slag	CEL (4)
ARMCO iron	–	0.02	–	–	–	–	–	–	–	–	–	INCO (3)
AISI 1010	0.12	0.50	0.004	0.023	0.060	–	–	–	–	–	–	CEL (4)
AISI 1010	0.11	0.52	0.016	0.024	0.048	–	–	–	–	–	–	CEL (4)
AISI 1010	–	0.34	0.01	–	0.02	0.04	0.02	–	0.03	–	–	INCO (3)
AISI 1015	–	–	–	–	–	–	–	–	–	–	–	MEL (5)
Copper steel	–	0.40	0.01	–	0.02	0.01	0.03	–	0.28	–	–	INCO (3)
ASTM A36	0.24	0.70	0.011	0.027	0.055	–	–	–	–	–	–	CEL (4)
ASTM A36	0.20	0.55	0.010	0.020	0.064	–	–	–	–	–	–	CEL (4)
ASTM A387-D	0.06	0.49	0.013	0.021	0.24	–	2.20	1.02	–	–	–	CEL (4)
Plow steel[b]												CEL (4)
HSLA No. 1[c]	0.18	0.86	0.014	0.023	0.28	0.05	0.64	0.18	–	–	0.047 V 0.0028 B 0.020 Ti	CEL (4)
HSLA No. 2	0.12	0.30	0.015	0.025	0.27	2.34	1.25	0.20	0.17	–	–	CEL (4)
HSLA No. 3	0.17	0.28	0.020	0.018	0.20	2.96	1.76	0.40	–	–	–	CEL (4)
HSLA No. 3	0.10	0.28	0.014	0.010	0.25	2.91	1.59	0.52	–	–	–	CEL (4)
HSLA No. 3	–	–	–	–	–	–	–	–	–	–	–	Boeing (6)
HSLA No. 4	0.07	0.38	0.11	0.025	0.54	0.31	0.88	–	0.28	–	–	CEL (4)
HSLA No. 4	–	0.36	0.08	–	0.41	0.32	0.72	–	0.38	–	–	INCO (3)
HSLA No. 5	0.14	0.78	0.020	0.025	0.23	0.74	0.56	0.42	0.22	–	0.36 V 0.0041 B	CEL (4)
HSLA No. 5	0.20	0.83	–	0.03	–	0.38	0.54	0.21	0.45	–	0.35 V	NADC (7)
HSLA No. 5[d]												INCO (3)
HSLA No. 6	0.26	0.13	0.007	0.008	0.01	3.07	1.43	0.97	–	–	0.07 Cb	CEL (4)
HSLA No. 6	–	–	–	–	–	–	–	–	–	–	–	Boeing (6)
HSLA No. 7	–	0.43	0.12	–	0.13	0.54	–	–	1.0	–	–	INCO (3)
HSLA No. 8	–	0.24	0.03	–	0.004	0.47	0.51	–	0.51	–	–	INCO (3)
HSLA No. 9	–	0.75	0.12	–	0.55	1.00	0.70	–	0.50	–	–	INCO (3)
HSLA No. 10	–	0.63	0.01	–	–	0.99	–	–	1.42	–	–	INCO (3)

Continued

Table 3. Continued.

Alloy	C	Mn	P	S	Si	Ni	Cr	Mo	Cu	Co	Other	Source[a]
HSLA No. 11	–	0.69	0.08	–	–	0.50	0.26	–	0.30	–	–	INCO (3)
HSLA No. 12	0.14	0.26	0.011	0.009	0.27	2.60	1.55	0.46	–	–	0.02 V	CEL (4)
HSLA No. 13	0.23	1.18	0.04	0.05	0.30	–	–	–	–	–	0.02 Cb + V 0.015 N	CEL (4)
HS No. 1[e]	0.11	0.78	0.008	0.006	0.29	5.03	0.56	0.42	–	–	0.05 V	CEL (4)
HS No. 1A	0.12	0.84	0.003	0.005	0.32	4.91	0.56	0.48	–	–	0.07 V 0.021 Al 0.003 O 0.010 N	CEL (4)
HS No. 2	0.002	0.018	0.004	0.005	0.05	12.20	5.07	3.12	–	–	0.21 Ti 0.25 Al	CEL (4)
HS No. 2A	0.032	0.073	0.007	0.013	0.062	12.04	5.04	3.39	–	–	0.24 Ti 0.41 Al 0.008 N	USS (8)
HS No. 3	0.28	0.29	0.005	0.005	0.10	8.26	0.53	0.47	–	3.82	0.15 V	CEL (4)
HS No. 3A	0.24	0.19	0.004	0.010	0.01	8.36	0.47	0.47	–	3.90	0.06 V	CEL (4)
HS No. 4	0.11	0.38	0.006	0.013	0.27	2.76	1.23	0.30	–	–	0.10 V 0.035 Al	CEL (4)
HS No. 5	0.11	0.06	0.005	0.005	0.067	9.91	2.20	0.98	–	8.00	0.003 Al 0.001 O 0.002 N	CEL (4)
HS No. 6	0.18	0.30	0.007	0.004	0.02	9.18	0.77	1.01	0.13	4.39	0.09 V	CEL (4)
12 Ni, maraging	–	–	–	–	–	–	–	–	–	–	–	Boeing (6)
18 Ni, maraging	0.02	0.10	0.005	0.007	0.14	17.92	–	4.78	–	8.75	0.003 B 0.94 Ti 0.17 Al	CEL (4)
18 Ni, maraging	0.02	0.05	0.005	0.010	0.06	18.17	–	4.85	0.10	8.13	0.36 Ti 0.08 Al	CEL (4)
18 Ni, maraging	–	–	–	–	–	18.0	–	5.0	–	7.0	–	INCO (3)
18 Ni, maraging	–	–	–	–	–	18.0	–	4.72	–	7.85	–	NADC (7)
18 Ni, maraging	–	–	–	–	–	–	–	–	–	–	–	Boeing (6)
1.5% Ni	–	–	–	–	–	–	–	–	–	–	–	INCO (3)

Continued

Table 3. Continued.

Alloy	C	Mn	P	S	Si	Ni	Cr	Mo	Cu	Co	Other	Source[a]
3% Ni	–	–	–	–	–	–	–	–	–	–	–	INCO (3)
5% Ni	–	–	–	–	–	–	–	–	–	–	–	INCO (3)
9% Ni	–	–	–	–	–	–	–	–	–	–	–	INCO (3)
AISI 4130	0.29	0.42	–	–	–	–	0.90	0.18	–	–	–	NADC (7)
AISI 4140	0.42	0.87	0.016	0.032	0.24	–	0.87	0.22	–	–	–	Shell (9)
AISI 4340	0.40	0.73	0.013	0.014	0.27	1.77	0.82	0.24	–	–	–	CEL (4)
AISI 4340	0.33	0.65	–	–	–	2.0	0.73	0.26	0.11	–	–	NADC (7)
AISI 502	0.06	0.48	0.020	0.010	0.33	–	4.75	0.55	–	–	–	CEL (4)
AISI 502	0.06	0.5	–	–	–	0.4	5.2	0.5	–	–	–	INCO (3)
D6AC	0.45	–	–	–	–	0.6	1.1	1.1	–	–	0.1 V	Boeing (6)
Gray cast iron	–	–	–	–	–	–	–	–	–	–	–	INCO (3)
Ni cast iron	–	0.68	–	–	2.47	1.56	–	–	–	–	–	INCO (3)
Ni-Cr cast iron No. 1	–	0.73	–	–	1.64	1.66	0.60	–	–	–	–	INCO (3)
Ni-Cr cast iron No. 2	–	0.86	–	–	1.99	3.22	0.98	–	–	–	–	INCO (3)
Ductile cast iron No. 1	–	0.35	–	–	2.50	0.91	–	–	–	–	–	INCO (3)
Ductile cast iron No. 2	–	0.34	–	–	2.24	–	–	–	–	–	–	INCO (3)
Si cast iron	–	–	–	–	14.5	–	–	–	–	–	–	INCO (3)
Si-Mo cast iron	–	–	–	–	14.0	–	–	3.0	–	–	–	INCO (3)
Si-Mo cast iron	0.4-1.0	0.4-1.0	–	–	14-17	–	–	3.5	–	–	–	NADC (7)
Austenitic cast iron, Type 1	–	1.4	–	–	2.05	15.8	1.79	–	6.71	–	–	INCO (3)
Austenitic cast iron, Type 2	–	1.01	–	–	2.29	18.2	2.04	–	–	–	–	INCO (3)
Austenitic cast iron, Type 3	–	0.6	–	–	1.15	28.4	2.87	–	–	–	–	INCO (3)
Austenitic cast iron, Type 4	–	0.56	–	–	5.34	29.7	4.94	–	–	–	–	INCO (3)
Austenitic cast iron, Type 4	2.13	0.79	–	–	5.60	29.98	5.02	–	0.16	–	–	CEL (4)
Austenitic cast iron D-2	–	0.94	–	–	3.0	21.4	2.26	–	–	–	–	INCO (3)
Austenitic cast iron D-2b	–	0.96	–	–	2.0	20.8	3.19	–	–	–	–	INCO (3)
Austenitic cast iron D-2c	2.45	2.12	0.017	–	2.38	22.34	0.08	–	–	–	–	CEL (4)
Austenitic cast iron D-3	–	0.5	–	–	1.83	29.8	2.70	–	–	–	–	INCO (3)

Continued

Table 3. Continued.

Alloy	C	Mn	P	S	Si	Ni	Cr	Mo	Cu	Co	Other	Source[a]
Austenitic cast iron, hardenable	–	–	–	–	–	–	–	–	–	–	–	INCO (3)
Galvanized steel, 1 oz/ft^2 [f]	0.15 max	0.25-0.60	0.040 max	0.050 max	–	–	–	–	–	–	–	CEL (4)
Aluminized steel, Type 2, 1.03 oz/ft^2	–	–	–	–	–	–	–	–	–	–	–	CEL (4)

[a]Numbers refer to references at end of report.

[b]No composition limits.

[c]High-strength, low-alloy steel.

[d]With mill scale.

[e]High-strength steel.

[f]ASTM Specification A526-64T, 18 gage.

Table 4. Condition of the Steels, As Received

Alloy	Condition
Wrought iron	As fabricated pipe
Armco iron	Mill finish, anodically cleaned
AISI C1010	Hot rolled (mill) and pickled (laboratory)
AISI 1015	Grit blasted
ASTM A36	Hot rolled (mill) and pickled (laboratory)
ASTM A387-D	Hot rolled (mill) and pickled (laboratory)
HSLA No. 1	Water quenched from 1,650°F to 1,750°F and tempered at 1,100°F to 1,275°F (mill), blast cleaned (laboratory)
HSLA No. 2	Hot rolled and pickled
HSLA No. 3	Water quenched from 1,650°F and tempered at 1,150°F to 1,200°F (mill), blast cleaned (laboratory)
HSLA No. 4	Hot rolled (mill) and pickled (laboratory)
HSLA No. 5	Water quenched from 1,650°F to 1,750°F and tempered at 1,150°F to 1,275°F (mill), blast cleaned (laboratory)
HSLA No. 6	Consumable electrode vacuum melt, hot rolled, annealed, cleaned and oiled
HSLA No. 12	Quenched and tempered
HS No. 1	Quenched and tempered
HS No. 2	Solution annealed and aged
HS No. 3	Consumable electrode vacuum melt, hot rolled, annealed, cleaned and oiled
AISI 4130	Quenched and tempered
AISI 4140	Austenized at 1,550°F for 0.7 hr, oil quenched to room temperature, tempered at 900°F for 1 hr, air cooled to room temperature
AISI 4340 (200 ksi)	Oil quenched from 1,550°F, tempered for 1 hr at 750°F, blast cleaned (laboratory)
AISI 4340 (150 ksi)	Oil quenched from 1,550°F, tempered for 1 hr at 1,050°F, blast cleaned (laboratory)
AISI 502	Annealed and pickled, No. 1 sheet finish (mill)
18% Ni, maraging (0.202)	Electric furnace air melt, air cast, annealed, desealed and oiled

Continued

Table 4. Continued.

Alloy	Condition
18% Ni, maraging (0.082)	Electric furnace air melt, air cast, annealed, desealed and oiled (mill); CEL unwelded, aged at 900^{o}F for 3 hr, air cooled, then welded
18% Ni, maraging	Electric furnace air melt, air cast, annealed, aged at 950^{o}F for 3 hr, air cooled, as rolled surfaces
18% Ni, maraging	Electric furnace air melt, air cast, annealed, aged at 950^{o}F for 3 hr, air cooled, surfaces ground to RMS-125
Austenitic cast iron, Type 4	As cast
Nodular austenitic cast iron, Type D-2c	As cast
Galvanized steel, 18 gage	1.0 oz/ft^2
Aluminized steel, Type 2	Commercial quality, 1.03 oz/ft^2

Table 5. Corrosion Rates of Irons and Steels

Alloy	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)[a]		Type of Corrosion[c]	Source[d]
			W[b]	M[b]		
Armco iron	123	5,640	3.1	2.4	U	INCO (3)
Armco iron	403	6,780	1.5	0.5[e]	U	INCO (3)
Armco iron	751	5,640	0.8	0.7	G	INCO (3)
Armco iron	1,064	5,300	0.7	1.9[e]	U	INCO (3)
Armco iron	197	2,340	1.9	0.9	G	INCO (3)
Armco iron	402	2,370	1.4	1.4	G	INCO (3)
Armco iron	181	5	6.9	–	U, CR[f]	INCO (3)
Armco iron	366	5	7.1	–	G	INCO (3)
Wrought iron	123	5,640	2.6	–	U	CEL (4)
Wrought iron	403	6,780	1.4	1.2	U	CEL (4)
Wrought iron	751	5,640	0.9	–	U	CEL (4)
Wrought iron	1,064	5,300	0.6	–	U	CEL (4)
Wrought iron	197	2,340	2.0	1.2	U	CEL (4)
Wrought iron	402	2,370	1.5	1.5	G	CEL (4)
Wrought iron	181	5	5.3	–	U	CEL (4)
Wrought iron	364	5	4.8	–	G	CEL (4)
Wrought iron	723	5	4.0	–	G	CEL (4)
Wrought iron	763	5	4.8	–	G	CEL (4)
AISI 1010	123	5,640	3.0	2.2	U	CEL (4)
AISI 1010	123	5,640	2.4	1.5	U	INCO (3)
AISI 1010	403	6,780	1.5	1.7	U	CEL (4)
AISI 1010	403	6,780	2.3	0.5	G	INCO (3)
AISI 1010	751	5,640	0.9	–	U	CEL (4)
AISI 1010	751	5,640	0.8	0.6	G	INCO (3)
AISI 1010	1,064	5,300	0.8	–	U	CEL (4)
AISI 1010	1,064	5,300	1.1	1.0	U	CEL (4)
AISI 1010	1,064	5,300	0.9	0.5	U	INCO (3)
AISI 1010	197	2,340	1.5	1.7	U	CEL (4)
AISI 1010	197	2,340	1.7	0.6	G	INCO (3)
AISI 1010	402	2,370	1.2	1.1	U	CEL (4)
AISI 1010	402	2,370	1.1	1.1	G	INCO (3)
AISI 1010	181	5	9.1	–	U	CEL (4)
AISI 1010	181	5	9.0	–	G	INCO (3)
AISI 1010	366	5	8.0	–	G	INCO (3)
AISI 1010	398	5	8.2	–	U	CEL (4)
AISI 1010	588	5	8.9	–	G	CEL (4)
AISI 1015	123	5,640	3.0	–	U	MEL (5)
AISI 1015	751	5,640	1.7	–	U	MEL (5)
AISI 1015	1,064	5,300	0.6	–	U	MEL (5)
AISI 1015[g]	386	5	5.3	–	G	MEL (5)
Copper steel	123	5,640	1.9	1.6	U	INCO (3)
Copper steel	403	6,780	2.1	0.7	G	INCO (3)
Copper steel	751	5,640	1.4	0.6	G	INCO (3)
Copper steel	1,064	5,300	0.5	0.4	U	INCO (3)
Copper steel	197	2,340	2.0	0.5	G	INCO (3)
Copper steel	402	2,370	1.1	1.2	U	INCO (3)
Copper steel	181	5	9.0	–	G	INCO (3)
Copper steel	366	5	6.0	–	G	INCO (3)

Continued

Table 5. Continued

Alloy	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)[a]		Type of Corrosion[c]	Source[d]
			W[b]	M[b]		
ASTM A36	123	5,640	3.1	2.4	U	CEL (4)
ASTM A36	403	6,780	1.5	1.8	U	CEL (4)
ASTM A36	751	5,640	0.9	–	U	CEL (4)
ASTM A36	1,064	5,300	0.6	–	U	CEL (4)
ASTM A36	197	2,340	1.7	1.7	U	CEL (4)
ASTM A36	402	2,370	1.3	1.5	U	CEL (4)
ASTM A36	181	5	10.7	–	G, C (8)	CEL (4)
ASTM A36	398	5	6.2	–	G	CEL (4)
ASTM A36	540	5	6.3	–	G	CEL (4)
ASTM A36	588	5	5.8	–	G	CEL (4)
ASTM A387-D	123	5,640	3.0	2.3	U	CEL (4)
ASTM A387-D	403	6,780	2.0	1.9	U	CEL (4)
ASTM A387-D	751	5,640	0.9	0.9	U	CEL (4)
ASTM A387-D	197	2,340	1.8	2.0	U	CEL (4)
ASTM A387-D	402	2,370	1.3	1.3	U	CEL (4)
HSLA No. 1	123	5,640	2.9	2.2	U	CEL (4)
HSLA No. 1	403	6,780	2.0	1.2	U	CEL (4)
HSLA No. 1	751	5,640	0.9	–	U	CEL (4)
HSLA No. 1	1,064	5,300	0.6	–	U	CEL (4)
HSLA No. 1	1,064	5,300	0.6	0.7	U	CEL (4)
HSLA No. 1	197	2,340	1.4	1.4	U	CEL (4)
HSLA No. 1	402	2,370	1.0	1.0	U	CEL (4)
HSLA No. 1	181	5	9.7	–	G, P	CEL (4)
HSLA No. 1	398	5	5.2	–	G, P	CEL (4)
HSLA No. 1	588	5	4.7	–	G, P	CEL (4)
HSLA No. 2	123	5,640	4.7	4.3	U	CEL (4)
HSLA No. 2	403	6,780	2.1	2.2	U	CEL (4)
HSLA No. 2	751	5,640	0.9	–	U	CEL (4)
HSLA No. 2	1,064	5,300	0.5	–	U	CEL (4)
HSLA No. 2	197	2,340	1.4	1.4	U	CEL (4)
HSLA No. 2	197	2,340	1.1	–	G	Boeing (6)
HSLA No. 2	402	2,370	1.3	1.1	U	CEL (4)
HSLA No. 2	181	5	6.8	–	G, P	CEL (4)
HSLA No. 2	398	5	4.5	–	U, P	CEL (4)
HSLA No. 2	540	5	4.4	–	G, P	CEL (4)
HSLA No. 3	1,064	5,300	0.7	–	U	CEL (4)
HSLA No. 4	123	5,640	3.6	–	U	CEL (4)
HSLA No. 4	123	5,640	4.3	1.8	U, C (9)	INCO (3)
HSLA No. 4	403	6,780	3.3	2.3	U	CEL (4)
HSLA No. 4	403	6,780	2.1	0.4	G	INCO (3)
HSLA No. 4	751	5,640	1.2	–	U	CEL (4)
HSLA No. 4	751	5,640	0.9	0.7	G	INCO (3)
HSLA No. 4	1,064	5,300	0.3	–	U	CEL (4)
HSLA No. 4	1,064	5,300	1.1	–	U	CEL (4)
HSLA No. 4	1,064	5,300	0.6	0.6	U	INCO (3)
HSLA No. 4	197	2,340	1.4	0.9	U	CEL (4)
HSLA No. 4	197	2,340	2.2	0.7	G	INCO (3)
HSLA No. 4	402	2,370	1.1	1.1	G	CEL (4)

Continued

Table 5. Continued

Alloy	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)[a]		Type of Corrosion[c]	Source[d]
			W[b]	M[b]		
HSLA No. 4	402	2,370	1.3	1.0	G	INCO (3)
HSLA No. 4	181	5	11.0	–	G	INCO (3)
HSLA No. 4	366	5	8.0	–	G	INCO (3)
HSLA No. 5	123	5,640	3.1	1.6	U	CEL (4)
HSLA No. 5	123	5,640	6.0	3.5	E	INCO (3)
HSLA No. 5	403	6,780	2.7	1.8	U	CEL (4)
HSLA No. 5	403	6,780	7.4	0.2	S-E, P (3)	INCO (3)
HSLA No. 5[b]	403	6,780	3.7	–	G	NADC (7)
HSLA No. 5	751	5,640	1.4	0.9	U	CEL (4)
HSLA No. 5	751	5,640	3.1	3.2	G, S-E	INCO (3)
HSLA No. 5	1,064	5,300	0.9	–	U	CEL (4)
HSLA No. 5	1,064	5,300	0.7	1.0	U	CEL (4)
HSLA No. 5	1,064	5,300	0.9	1.0	U	INCO (3)
HSLA No. 5	197	2,340	1.4	1.5	U	CEL (4)
HSLA No. 5	197	2,340	3.3	0.9	E, I-P	INCO (3)
HSLA No. 5	197	2,340	2.5	–	U	NADC (7)
HSLA No. 5	402	2,370	1.1	1.3	U	CEL (4)
HSLA No. 5	402	2,370	1.4	1.3	U, G	INCO (3)
HSLA No. 5[b]	402	2,370	1.1	–	G	NADC (7)
HSLA No. 5	181	5	8.9	–	U	CEL (4)
HSLA No. 5	181	5	11.0	–	G	INCO (3)
HSLA No. 5	366	5	8.0	–	G	INCO (3)
HSLA No. 5	398	5	6.0	–	G, P	CEL (4)
HSLA No. 5	540	5	5.4	–	G, P	CEL (4)
HSLA No. 6	197	2,340	1.4	–	G	Boeing (6)
HSLA No. 6	402	2,370	0.9	0.9	U	CEL (4)
HSLA No. 7	123	5,640	3.5	2.1	C (4), U	INCO (3)
HSLA No. 7	403	6,780	1.5	0.3	G	INCO (3)
HSLA No. 7	751	5,640	0.8	1.3	G	INCO (3)
HSLA No. 7	1,064	5,300	0.8	0.6	U	INCO (3)
HSLA No. 7	197	2,340	2.3	0.6	G	INCO (3)
HSLA No. 7	402	2,370	1.4	1.1	G	INCO (3)
HSLA No. 7	181	5	11.0	–	G	INCO (3)
HSLA No. 7	366	5	8.0	–	G	INCO (3)
HSLA No. 8	123	5,640	3.8	2.3	U	INCO (3)
HSLA No. 8	403	6,780	2.3	0.3	G	INCO (3)
HSLA No. 8	751	5,640	1.2	0.8	G	INCO (3)
HSLA No. 8	1,064	5,300	0.7	0.5	U	INCO (3)
HSLA No. 8	197	2,340	1.9	0.7	G	INCO (3)
HSLA No. 9	123	5,640	4.3	2.1	C (10)	INCO (3)
HSLA No. 9	403	6,780	2.5	0.3	G	INCO (3)
HSLA No. 9	751	5,640	1.4	1.0	G	INCO (3)
HSLA No. 9	1,064	5,300	0.6	0.5	U	INCO (3)
HSLA No. 9	197	2,340	1.6	0.6	G	INCO (3)
HSLA No. 10	123	5,640	4.1	2.5	C (9), U	INCO (3)
HSLA No. 10	403	6,780	1.8	0.5	G	INCO (3)
HSLA No. 10	751	5,640	0.9	1.1	G	INCO (3)

Continued

Table 5. Continued

Alloy	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)[a] W[b]	Corrosion Rate (mpy)[a] M[b]	Type of Corrosion[c]	Source[d]
HSLA No. 10	1,064	5,300	0.9	0.6	U	INCO (3)
HSLA No. 10	197	2,340	2.1	0.8	G	INCO (3)
HSLA No. 10	402	2,370	1.5	1.2	G	INCO (3)
HSLA No. 10	181	5	11.0	–	G	INCO (3)
HSLA No. 10	366	5	8.0	–	G	INCO (3)
HSLA No. 11	123	5,640	3.4	1.7	U	INCO (3)
HSLA No. 11	403	6,780	2.4	0.4	G	INCO (3)
HSLA No. 11	751	5,640	1.2	0.8	G	INCO (3)
HSLA No. 11	1,064	5,300	0.7	0.5	U	INCO (3)
HSLA No. 11	197	2,340	1.8	0.6	G	INCO (3)
HSLA No. 12	181	5	8.5	–	U, P	CEL (4)
HSLA No. 12	398	5	4.2	–	G, P	CEL (4)
HSLA No. 12	540	5	4.9	–	G, P	CEL (4)
HSLA No. 12	588	5	4.3	–	G, P	CEL (4)
HS No. 1	189	5,900	2.7	1.8	U	CEL (4)
HS No. 1[i]	189	5,900	2.7	1.8	U	CEL (4)
HS No. 1[j, k]	189	5,900	2.6	1.6	U	CEL (4)
HS No. 1	181	5	9.9	–	U	CEL (4)
HS No. 1	398	5	4.7	–	G, P	CEL (4)
HS No. 1	540	5	4.5	–	G, P	CEL (4)
HS No. 1	588	5	4.2	–	G, P	CEL (4)
HS No. 2	403	6,780	14.5 max,	9.0 avg[l]	P	USS (8)
HS No. 2, welded	403	6,780				
Base metal			13.5 max,	9.0 avg[l]	P	USS (8)
Weld metal			18.1 max,	13.5 avg[l]	P	USS (8)
HS No. 2	197	2,340	20.4 max,	16.7 avg[l]	P	USS (8)
HS No. 2, welded	197	2,340				
Base metal			29.6 max,	25.9 avg[l]	P	USS (8)
Weld metal			44.5 max,	38.9 avg[l]	P	USS (8)
HS No. 2	181	5	8.2	–	U	CEL (4)
HS No. 2	398	5	3.5	–	G, P	CEL (4)
HS No. 2	588	5	3.3	–	G, P	CEL (4)
HS No. 3	402	2,370	1.7	1.4	G	CEL (4)
HS No. 3	398	5	5.0	–	U, P	CEL (4)
HS No. 3	540	5	3.8	–	G, P	CEL (4)
HS No. 3	588	5	4.6	–	G, P	CEL (4)
HS No. 4	189	5,900	2.9	1.8	U	CEL (4)
HS No. 4[i]	189	5,900	2.3	1.5	U	CEL (4)
HS No. 4[j, k]	189	5,900	2.5	1.7	U, P	CEL (4)
HS No. 5	189	5,900	2.3	1.9	U	CEL (4)
HS No. 5[i]	189	5,900	2.0	1.7	U	CEL (4)
HS No. 5[j]	189	5,900	1.8	1.6	U	CEL (4)
HS No. 6	189	5,900	2.5	1.6	U	CEL (4)
HS No. 6[i]	189	5,900	2.8	1.5	U	CEL (4)
HS No. 6[j]	189	5,900	2.9	2.7	U	CEL (4)

Continued

Table 5. Continued

Alloy	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)[a]		Type of Corrosion[c]	Source[d]
			W[b]	M[b]		
12% Ni, maraging	197	2,340	2.4	–	G	Boeing (6)
18% Ni, maraging	123	5,640	3.6	–	U	NADC (7)
18% Ni, maraging	189	5,900	2.2	1.7	U	CEL (4)
18% Ni, maraging	403	6,780	1.6	–	U	NADC (7)
18% Ni, maraging	197	2,340	1.6	–	G	Boeing (6)
18% Ni, maraging	197	2,340	2.9	–	U	NADC (7)
18% Ni, maraging	402	2,370	1.3	–	U	NADC (7)
18% Ni, maraging	402	2,370	1.3	0.9	G	CEL (4)
18% Ni, maraging	402	2,370	1.5	0.8	G	INCO (3)
18% Ni, maraging (as rolled)	402	2,370	1.4	1.3	G	CEL (4)
18% Ni, maraging (machined)	402	2,370	1.3	1.2	G	CEL (4)
18% Ni, maraging	402	2,370	3.5	2.6	G	CEL (4)
18% Ni, maraging[b]	402	2,370	2.8	1.7	G	CEL (4)
18% Ni, maraging	181	5	5.4	–	U, P	CEL (4)
18% Ni, maraging	181	5	10.0	–	P	INCO (3)
18% Ni, maraging[m]	181	5	5.8	–	U	CEL (4)
18% Ni, maraging[b]	181	5	5.1	–	U	CEL (4)
18% Ni, maraging	366	5	7.0	–	P	INCO (3)
18% Ni, maraging	398	5	3.0	–	U, P	CEL (4)
18% Ni, maraging	588	5	3.1	–	G, C, P	CEL (4)
18% Ni, maraging[m]	364	5	4.0	–	G, P	CEL (4)
18% Ni, maraging[m]	723	5	3.5	–	G, P	CEL (4)
18% Ni, maraging[m]	763	5	4.1	–	G	CEL (4)
18% Ni, maraging[b]	364	5	4.0	–	P, WB(G)	CEL (4)
18% Ni, maraging[b]	723	5	3.3	–	G, P	CEL (4)
18% Ni, maraging[b]	763	5	3.9	–	G	CEL (4)
1.5% Ni steel	123	5,640	3.5	2.7	U	INCO (3)
1.5% Ni steel	403	6,780	1.7	0.8	G	INCO (3)
1.5% Ni steel	751	5,640	1.0	0.5	G	INCO (3)
1.5% Ni steel	1,064	5,300	0.7	0.7	U	INCO (3)
1.5% Ni steel	197	2,340	1.9	0.5	U	INCO (3)
1.5% Ni steel	402	2,370	1.5	1.2	U	INCO (3)
1.5% Ni steel	181	5	11.0	–	G	INCO (3)
1.5% Ni steel	366	5	8.0	–	G	INCO (3)
3% Ni steel	123	5,640	3.4	3.0	U	INCO (3)
3% Ni steel	403	6,780	1.9	0.4	C (2), G	INCO (3)
3% Ni steel	751	5,640	0.9	0.9	G	INCO (3)
3% Ni steel	1,064	5,300	0.9	0.6	U	INCO (3)
3% Ni steel	197	2,340	1.7	0.4	G	INCO (3)
3% Ni steel	402	2,370	1.3	1.0	G	INCO (3)
3% Ni steel	181	5	11.0	–	G	INCO (3)
3% Ni steel	366	5	8.0	–	G	INCO (3)
5% Ni steel	123	5,640	2.8	2.8	U	INCO (3)
5% Ni steel	403	6,780	2.8	0.4	C (6), G	INCO (3)
5% Ni steel	751	5,640	1.1	0.8	G	INCO (3)
5% Ni steel	1,064	5,300	0.7	0.5	U	INCO (3)
5% Ni steel	197	2,340	1.7	0.4	G	INCO (3)
5% Ni steel	402	2,370	1.3	1.1	U	INCO (3)

Continued

Table 5. Continued

Alloy	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)[a]		Type of Corrosion[c]	Source[d]
			W[b]	M[b]		
5% Ni steel	181	5	8.0	–	G	INCO (3)
5% Ni steel	366	5	7.0	–	G	INCO (3)
9% Ni steel	123	5,640	5.6	5.6	U	INCO (3)
9% Ni steel	403	6,780	2.9	0.5	C (9), G	INCO (3)
9% Ni steel	751	5,640	1.1	4.5	G	INCO (3)
9% Ni steel	1,064	5,300	4.6	1.2	U	INCO (3)
9% Ni steel	197	2,340	1.9	0.4	G	INCO (3)
9% Ni steel	402	2,370	1.6	1.3	G	INCO (3)
9% Ni steel	181	5	10.0	–	I-P	INCO (3)
9% Ni steel	366	5	8.0	–	G	INCO (3)
AISI 4130 (100 ksi)	123	5,640	2.3	–	U	NADC (7)
AISI 4130 (160 ksi)	123	5,640	3.1	–	U	NADC (7)
AISI 4130 (100 ksi)	403	6,780	2.7	–	U	NADC (7)
AISI 4130 (100 ksi)	751	5,640	2.2	–	U	NADC (7)
AISI 4130 (100 ksi)	1,064	5,300	1.3	–	U	NADC (7)
AISI 4130 (100 ksi)	197	2,340	2.3	–	U	NADC (7)
AISI 4130 (100 ksi)	402	2,370	1.0	–	U	NADC (7)
AISI 4140	402	2,370	1.4	1.6	G, C (12)	Shell (9)
AISI 4340 (150 ksi)	123	5,640	2.7	–	U	CEL (4)
AISI 4340 (150 ksi)	403	6,780	2.2	1.7	U	CEL (4)
AISI 4340 (150 ksi)	403	6,780	2.2	1.5	U	CEL (4)
AISI 4340	403	6,780	1.6	–	U	NADC (7)
AISI 4340 (150 ksi)	751	5,640	0.8	–	U	CEL (4)
AISI 4340 (150 ksi)	197	2,340	1.9	1.3	U	CEL (4)
AISI 4340 (150 ksi)	197	2,340	1.6	1.8	U	CEL (4)
AISI 4340	197	2,340	4.1	–	U	NADC (7)
AISI 4340	402	2,370	1.0	–	U	NADC (7)
AISI 4340 (150 ksi)	402	2,370	1.2	1.3	U	CEL (4)
AISI 4340 (200 ksi)	123	5,640	2.8	–	U	CEL (4)
AISI 4340 (200 ksi)	403	6,780	2.0	1.9	U	CEL (4)
AISI 4340 (200 ksi)	403	6,780	2.0	1.8	U	CEL (4)
AISI 4340 (200 ksi)	751	5,640	0.9	–	U	CEL (4)
AISI 4340 (200 ksi)	197	2,340	1.4	1.4	U	CEL (4)
AISI 4340 (200 ksi)	197	2,340	2.1	2.2	U	CEL (4)
AISI 4340 (200 ksi)	402	2,370	1.4	1.4	U	CEL (4)
AISI 502	123	5,640	5.9	4.3	P, C (21)	CEL (4)
AISI 502	123	5,640	4.3	4.6	P (12), E, C (24)	INCO (3)
AISI 502	403	6,780	2.3	2.6	C (22)	CEL (4)
AISI 502	403	6,780	13.2	0.4	P, C (35), G	INCO (3)
AISI 502	751	5,640	2.8	–	E, C (50), P (36)	CEL (4)
AISI 502	751	5,640	4.4	2.5	C (PR)	INCO (3)
AISI 502	1,064	5,300	2.6	–	C	CEL (4)
AISI 502	1,064	5,300	1.9	1.7	P, C	CEL (4)
AISI 502	1,064	5,300	3.0	1.1	C (PR)	INCO (3)

Continued

Table 5. Continued

Alloy	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)[a] W[b]	Corrosion Rate (mpy)[a] M[b]	Type of Corrosion[c]	Source[d]
AISI 502	197	2,340	1.4	1.2	P, C (23)	CEL (4)
AISI 502	197	2,340	3.1	0.2	E, C (20)	INCO (3)
AISI 502	402	2,370	0.8	0.6	P, C (16)	CEL (4)
AISI 502	402	2,370	3.1	0.1	P, C (PR)	INCO (3)
AISI 502	181	5	7.0	–	P (18)	CEL (4)
AISI 502	181	5	13.0	–	G	INCO (3)
AISI 502	366	5	8.0	–	G	INCO (3)
AISI 502	398	5	4.4	–	G, P (30)	CEL (4)
AISI 502	540	5	4.1	–	G, P	CEL (4)
D6AC	197	2,340	1.5	–	G	Boeing (6)
Gray cast iron	123	5,640	4.2	3.0	U	INCO (3)
Gray cast iron	403	6,780	1.8	1.3	U	INCO (3)
Gray cast iron	751	5,640	1.2	1.0	G	INCO (3)
Gray cast iron	1,064	5,300	0.8	0.5	U	INCO (3)
Gray cast iron	197	2,340	2.0	0.3	G	INCO (3)
Gray cast iron	402	2,370	1.7	2.0	U	INCO (3)
Gray cast iron	366	5	2.6	–	G	INCO (3)
Ni cast iron	123	5,640	4.4	3.4	U	INCO (3)
Ni cast iron	403	6,780	2.9	1.5	U, M	INCO (3)
Ni cast iron	751	5,640	1.4	1.1	G	INCO (3)
Ni cast iron	1,064	5,300	0.9	1.5	G	INCO (3)
Ni cast iron	197	2,340	2.2	0.3	G	INCO (3)
Ni cast iron	402	2,370	1.5	1.5	U	INCO (3)
Ni cast iron	181	5	8.5	–	U	INCO (3)
Ni cast iron	366	5	7.6	–	G	INCO (3)
Ni-Cr cast iron No. 1	123	5,640	4.3	3.3	U	INCO (3)
Ni-Cr cast iron No. 1	403	6,780	1.7	1.2	U	INCO (3)
Ni-Cr cast iron No. 1	751	5,640	1.3	0.9	G	INCO (3)
Ni-Cr cast iron No. 1	1,064	5,300	0.8	0.7	U	INCO (3)
Ni-Cr cast iron No. 1	197	2,340	1.9	0.3	G	INCO (3)
Ni-Cr cast iron No. 1	402	2,370	1.8	1.4	U	INCO (3)
Ni-Cr cast iron No. 1	181	5	6.7	–	U	INCO (3)
Ni-Cr cast iron No. 1	366	5	5.2	–	U	INCO (3)
Ni-Cr cast iron No. 2	123	5,640	4.3	3.7	U	INCO (3)
Ni-Cr cast iron No. 2	403	6,780	1.8	1.4	U	INCO (3)
Ni-Cr cast iron No. 2	751	5,640	1.3	1.1	G	INCO (3)
Ni-Cr cast iron No. 2	1,064	5,300	0.7	0.7	U	INCO (3)
Ni-Cr cast iron No. 2	197	2,340	1.9	0.3	G	INCO (3)
Ni-Cr cast iron No. 2	402	2,370	1.8	1.1	U	INCO (3)
Ni-Cr cast iron No. 2	181	5	8.5	–	U	INCO (3)
Ni-Cr cast iron No. 2	366	5	4.9	–	G	INCO (3)
Ductile cast iron No. 1	123	5,640	3.1	3.0	U	INCO (3)
Ductile cast iron No. 1	403	6,780	3.4	1.0	G	INCO (3)
Ductile cast iron No. 1	751	5,640	1.0	0.9	G	INCO (3)
Ductile cast iron No. 1	1,064	5,300	0.6	0.7	U	INCO (3)
Ductile cast iron No. 1	197	2,340	1.9	0.7	G	INCO (3)
Ductile cast iron No. 1	402	2,370	1.9	1.7	U	INCO (3)

Continued

Table 5. Continued

Alloy	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)[a]		Type of Corrosion[c]	Source[d]
			W[b]	M[b]		
Ductile cast iron No. 1	181	5	10.0	–	U	INCO (3)
Ductile cast iron No. 1	366	5	6.2	–	CR (24)	INCO (3)
Ductile cast iron No. 2	123	5,640	3.9	2.9	U	INCO (3)
Ductile cast iron No. 2	403	6,780	2.9	0.9	G, M	INCO (3)
Ductile cast iron No. 2	751	5,640	1.0	0.8	G	INCO (3)
Ductile cast iron No. 2	1,064	5,300	0.8	0.6	U	INCO (3)
Ductile cast iron No. 2	197	2,340	2.3	0.5	G	INCO (3)
Ductile cast iron No. 2	402	2,370	1.8	1.4	U	INCO (3)
Ductile cast iron No. 2	181	5	10.0	–	U	INCO (3)
Ductile cast iron No. 2	366	5	7.1	–	G	INCO (3)
Silicon cast iron	123	5,640	<0.1	<0.1	NC	INCO (3)
Silicon cast iron	403	6,780	<0.1	<0.1	NC	INCO (3)
Silicon cast iron	751	5,640	<0.1	<0.1	NC	INCO (3)
Silicon cast iron	1,064	5,300	<0.1	<0.1	NC	INCO (3)
Silicon cast iron	197	2,340	<0.1	<0.1	NC	INCO (3)
Silicon cast iron	402	2,370	<0.1	<0.1	NC	INCO (3)
Silicon cast iron	181	5	<0.1	–	E	INCO (3)
Silicon cast iron	366	5	<0.1	–	ET	INCO (3)
Si-Mo cast iron	123	5,640	<0.1	<0.1	NC	INCO (3)
Si-Mo cast iron	403	6,780	<0.1	<0.1	NC	INCO (3)
Si-Mo cast iron	403	6,780	0.1	–	U	NADC (7)
Si-Mo cast iron	751	5,640	<0.1	<0.1	NC	INCO (3)
Si-Mo cast iron	1,064	5,300	<0.1	<0.1	NC	INCO (3)
Si-Mo cast iron	197	2,340	<0.1	<0.1	NC	INCO (3)
Si-Mo cast iron	402	2,370	<0.1	<0.1	NC	INCO (3)
Si-Mo cast iron	402	2,370	<0.1	–	U	NADC (7)
Si-Mo cast iron	181	5	<0.1	–	NC	INCO (3)
Si-Mo cast iron	366	5	<0.1	–	ET	INCO (3)
Austenitic cast iron, Type 1	123	5,640	2.4	2.4	G	INCO (3)
Austenitic cast iron, Type 1	403	6,780	1.0	0.2	U	INCO (3)
Austenitic cast iron, Type 1	751	5,640	0.5	0.8	G	INCO (3)
Austenitic cast iron, Type 1	1,064	5,300	0.5	0.6	U	INCO (3)
Austenitic cast iron, Type 1	197	2,340	1.8	1.1	G	INCO (3)
Austenitic cast iron, Type 1	402	2,370	1.5	0.6	U	INCO (3)
Austenitic cast iron, Type 1	181	5	4.1	–	U	INCO (3)
Austenitic cast iron, Type 1	366	5	2.7	–	U	INCO (3)
Austenitic cast iron, Type 2	123	5,640	2.4	2.2	G	INCO (3)
Austenitic cast iron, Type 2	403	6,780	2.2	0.2	U	INCO (3)
Austenitic cast iron, Type 2	751	5,640	1.5	1.6	G	INCO (3)
Austenitic cast iron, Type 2	1,064	5,300	1.4	1.0	G	INCO (3)
Austenitic cast iron, Type 2	197	2,340	1.3	1.1	G	INCO (3)
Austenitic cast iron, Type 2	402	2,370	1.1	0.7	U	INCO (3)
Austenitic cast iron, Type 2	181	5	5.8	–	U	INCO (3)
Austenitic cast iron, Type 2	366	5	2.9	–	U	INCO (3)
Austenitic cast iron, Type 3	123	5,640	1.9	1.7	G	INCO (3)
Austenitic cast iron, Type 3	403	6,780	1.8	<0.1	U	INCO (3)
Austenitic cast iron, Type 3	751	5,640	1.9	1.9	G	INCO (3)

Continued

Table 5. Continued

Alloy	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)[a]		Type of Corrosion[c]	Source[d]
			W[b]	M[b]		
Austenitic cast iron, Type 3	1,064	5,300	1.2	0.8	U	INCO (3)
Austenitic cast iron, Type 3	197	2,340	0.8	0.7	G	INCO (3)
Austenitic cast iron, Type 3	402	2,370	0.6	0.7	U	INCO (3)
Austenitic cast iron, Type 3	181	5	5.0	—	U	INCO (3)
Austenitic cast iron, Type 3	366	5	2.8	—	U	INCO (3)
Austenitic cast iron, Type 4	123	5,640	1.8	1.6	G	INCO (3)
Austenitic cast iron, Type 4	189	5,900	2.0	1.4	U	CEL (4)
Austenitic cast iron, Type 4	403	6,780	2.0	1.3	U	INCO (3)
Austenitic cast iron, Type 4	751	5,640	1.2	1.5	G	INCO (3)
Austenitic cast iron, Type 4	1,064	5,300	0.9	0.4	U	INCO (3)
Austenitic cast iron, Type 4	197	2,340	0.8	0.4	G	INCO (3)
Austenitic cast iron, Type 4	402	2,370	0.9	0.7	G	CEL (4)
Austenitic cast iron, Type 4	402	2,370	0.8	0.3	U	INCO (3)
Austenitic cast iron, Type 4	181	5	3.8	—	U	CEL (4)
Austenitic cast iron, Type 4	181	5	3.4	—	U	INCO (3)
Austenitic cast iron, Type 4	364	5	2.4	—	G	CEL (4)
Austenitic cast iron, Type 4	366	5	2.4	—	U	INCO (3)
Austenitic cast iron, Type 4	723	5	2.0	—	G	CEL (4)
Austenitic cast iron, Type 4	763	5	2.0	—	G	CEL (4)
Austenitic cast iron, D-2	123	5,640	2.6	2.4	G	INCO (3)
Austenitic cast iron, D-2	403	6,780	1.2	0.2	U	INCO (3)
Austenitic cast iron, D-2	751	5,640	1.3	1.5	G	INCO (3)
Austenitic cast iron, D-2	1,064	5,300	1.1	0.4	U	INCO (3)
Austenitic cast iron, D-2	197	2,340	1.2	0.2	G	INCO (3)
Austenitic cast iron, D-2	402	2,370	1.1	0.5	U	INCO (3)
Austenitic cast iron, D-2	181	5	4.3	—	G	INCO (3)
Austenitic cast iron, D-2	366	5	2.4	—	G	INCO (3)
Austenitic cast iron, D-2b	123	5,640	2.1	2.0	G	INCO (3)
Austenitic cast iron, D-2b	403	6,780	1.6	0.1	U	INCO (3)
Austenitic cast iron, D-2b	751	5,640	1.2	1.3	G	INCO (3)
Austenitic cast iron, D-2b	1,064	5,300	1.0	0.4	G	INCO (3)
Austenitic cast iron, D-2b	197	2,340	1.4	0.1	G	INCO (3)
Austenitic cast iron, D-2b	402	2,370	0.9	0.6	U	INCO (3)
Austenitic cast iron, D-2b	181	5	4.1	—	G	INCO (3)
Austenitic cast iron, D-2b	366	5	2.7	—	G	INCO (3)
Austenitic cast iron, D-2c	189	5,900	3.3	1.5	U	CEL (4)
Austenitic cast iron, D-2c	402	2,370	1.8	1.2	U	CEL (4)
Austenitic cast iron, D-2c	181	5	3.9	—	U	CEL (4)
Austenitic cast iron, D-2c	364	5	3.2	—	G	CEL (4)
Austenitic cast iron, D-2c	723	5	3.1	—	U	CEL (4)
Austenitic cast iron, D-2c	763	5	2.8	—	U	CEL (4)
Austenitic cast iron, D-3	123	5,640	1.9	2.2	G	INCO (3)
Austenitic cast iron, D-3	402	6,780	2.7	0.4	G	INCO (3)
Austenitic cast iron, D-3	751	5,640	2.1	1.9	G	INCO (3)
Austenitic cast iron, D-3	1,064	5,300	1.2	0.7	U	INCO (3)
Austenitic cast iron, D-3	197	2,340	0.9	0.2	G	INCO (3)
Austenitic cast iron, D-3	402	2,370	0.7	0.5	U	INCO (3)
Austenitic cast iron, D-3	181	5	4.3	—	G	INCO (3)

Continued

Table 5. Continued

Alloy	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)[a]		Type of Corrosion[c]	Source[d]
			W[b]	M[b]		
Austenitic cast iron, D-3	366	5	3.2	–	G	INCO (3)
Austenitic cast iron, hardenable	123	5,640	2.5	2.8	G	INCO (3)
Austenitic cast iron, hardenable	403	6,780	1.1	0.4	U	INCO (3)
Austenitic cast iron, hardenable	751	5,640	0.7	0.7	G	INCO (3)
Austenitic cast iron, hardenable	1,064	5,300	0.6	0.7	U	INCO (3)
Austenitic cast iron, hardenable	197	2,340	2.8	0.1	G	INCO (3)
Austenitic cast iron, hardenable	402	2,370	1.8	0.5	U	INCO (3)
Austenitic cast iron, hardenable	181	5	4.2	–	U	INCO (3)
Austenitic cast iron, hardenable	366	5	2.6	–	U	INCO (3)
Galvanized steel, 1 oz/ft^2 [n]	189	5,900	1.9	1.6	U	CEL (4)
Galvanized steel, 1 oz/ft^2	402	2,370	0.9	0.4	G	CEL (4)
Aluminized steel, 1 oz/ft^2 [o]	189	5,900	0.2	0.2	U	CEL (4)
Aluminized steel, 1 oz/ft^2 [p]	402	2,370	0.0	0.0	G	CEL (4)

[a] mpy = mils penetration per year calculated from weight loss.

[b] W = specimens exposed on sides of structure in seawater; M = specimens exposed in the base of the structure, partially embedded in the bottom sediment.

[c] Symbols signify the following types of corrosion:

- C = Crevice
- CR = Cratering
- E = Edge
- ET = Etched
- G = General
- I = Incipient
- M = Corroded at sediment line
- NC = No visible corrosion
- P = Pitting
- PR = Perforation
- S = Severe
- U = Uniform
- WB = Weld bead

Numbers after symbols refer to maximum depth in mils.

[d] Numbers refer to references at end of report.

[e] Corrosion accelerated below mud line.

[f] Single crater, 12 mils deep.

[g] Surface exposure at Francis L. LaQue Corrosion Laboratory, Wrightsville Beach, N.C.

[h] Welded.

[i] Transverse butt weld, weld bead same as plate.

[j] Circular weld bead, 3-in. diameter, in center of plate.

[k] Pitted, 154 mils maximum, 73.4 average (15 pits), water.

[l] Pitting rate, mpy.

[m] Heat treated 900°F, 3 hr, air cooled.

[n] Zinc coating completely gone.

[o] Aluminum coating 50% gone, mottled, bare steel in places.

[p] W = no rust, 78% aluminum coating remaining; M = no rust, 60% aluminum coating remaining.

Table 6. Inorganic Coatings on Steels

Alloy	Exposure (day)	Depth (ft)	Paint Coating	Condition After Exposure[a]	Source[b]
AISI 4130	123	5,640	Wash primer, MIL-C-8541	NPF	NADC (7)
	403	6,780	Epoxy primer, MIL-P-23377		
	1,064	5,300	Epoxy topcoat, MIL-C-22750		
	197	2,340			
	402	2,370			
AISI 4340	197	2,340	Wash primer, MIL-C-8541	NPF	NADC (7)
	402	2,370	Epoxy primer, MIL-P-23377		
			Epoxy topcoat, MIL-C-22750		
18% Ni, maraging	123	5,640	Wash primer, MIL-C-8541	NPF	NADC (7)
	403	6,780	Epoxy primer, MIL-P-23377		
	197	2,340	Epoxy topcoat, MIL-C-22750		
	402	2,370			
HSLA No. 5	197	2,340	Wash primer, MIL-C-8541	NPF	NADC (7)
			Epoxy primer, MIL-P-23377		
			Epoxy topcoat, MIL-C-22750		
HSLA No. 4	189	5,900	Zinc rich primer, 8 mils	RS	CEL (4)
HSLA No. 5	189	5,900	Zinc rich primer, 8 mils	RS	CEL (4)
HSLA No. 13	189	5,900	Zinc rich primer, 8 mils	RS	CEL (4)
HSLA No. 4	189	5,900	Wash primer, MIL-C-8514, 1 mil	NPF	CEL (4)
HSLA No. 5	189	5,900	Zinc rich primer, 8 mils	NPF	CEL (4)
HSLA No. 13	189	5,900	Epoxy topcoat, 6 mils	NPF	CEL (4)
HSLA No. 4	189	5,900	Epoxy tar primer, 8 mils	NPF	CEL (4)
HSLA No. 5	189	5,900	Epoxy tar topcoat, 8 mils	NPF	CEL (4)
HSLA No. 13	189	5,900		NPF	CEL (4)
HSLA No. 4	189	5,900	Epoxy tar primer, 8 mils	RS, IPF	CEL (4)
HSLA No. 5	189	5,900	Epoxy tar topcoat, aluminum pigmented, 8 mils	NPF	CEL (4)
HSLA No. 13	189	5,900		NPF	CEL (4)
HSLA No. 3	197	2,340	Epoxy primer, 162-Y-26, W.P. Fuller Co.	GC	Boeing (6)
HSLA No. 6	197	2,340	Topcoat, Epicote Finish 26-64, Unit	GC	Boeing (6)
12% Ni, maraging	197	2,340	Gull gray, National Lead Co.	FPF	Boeing (6)
18% Ni, maraging	197	2,340		FPF	Boeing (6)
D6AC	197	2,340		GC	Boeing (6)
HSLA No. 3	197	2,340	Polyurethane, laminar X500	PC	Boeing (6)
HSLA No. 6	197	2,340	Primer, 4-G-14, green	PB	Boeing (6)
12% Ni, maraging	197	2,340	Topcoat, 4-W-1A, white	NPF	Boeing (6)
18% Ni, maraging	197	2,340	Magna Coating and Chemical Co.	FPF	Boeing (6)
D6AC	197	2,340		GC	Boeing (6)

[a]Symbols signify the following:

GC = Good condition.
FPF = Few spots of paint failure.
IPF = Incipient paint failure.
NPF = No paint failure.
PC = Paint cracked.
PB = Paint blistered.
RS = Rust stains.

[b]Numbers indicate references at end of report.

Table 7. Stress Corrosion Tests

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed	Source[a]
0.2% Cu steel	–	33	123	5,640	3	0	NADC (7)
0.2% Cu steel	–	45	123	5,640	3	0	NADC (7)
0.2% Cu steel	–	64	123	5,640	3	0	NADC (7)
AISI 4130	51	30	403	6,780	3	0	NADC (7)
AISI 4130, Cd plated	51	30	403	6,780	3	0	NADC (7)
AISI 4130, Ni plated	51	30	403	6,780	3	0	NADC (7)
AISI 4130, Cu plated	51	30	403	6,780	3	0	NADC (7)
AISI 4130	51	30	751	5,640	3	0	NADC (7)
AISI 4130	51	30	197	2,340	3	0	NADC (7)
AISI 4130	85	50	403	6,780	3	0	NADC (7)
AISI 4130, Cd plated	85	50	463	6,780	3	0	NADC (7)
AISI 4130, Ni plated	85	50	403	6,780	3	0	NADC (7)
AISI 4130, Cu plated	85	50	403	6,780	3	0	NADC (7)
AISI 4130	85	50	751	5,640	3	0	NADC (7)
AISI 4130	127	75	403	6,780	3	0	NADC (7)
AISI 4130, Cd plated	127	75	403	6,780	3	0	NADC (7)
AISI 4130, Ni plated	127	75	403	6,780	3	0	NADC (7)
AISI 4130, Cu plated	127	75	403	6,780	3	0	NADC (7)
AISI 4130	127	75	751	5,640	3	0	NADC (7)
AISI 4130	127	75	197	2,340	3	0	NADC (7)
AISI 4130, Cd plated	127	75	197	2,340	3	0	NADC (7)
AISI 4130, Ni plated	127	75	197	2,340	3	1	NADC (7)
AISI 4130, Cu plated	127	75	197	2,340	3	0	NADC (7)
AISI 4140	120	–	402	2,370	6	0	Shell (9)
AISI 4140, bolts	90	–	402	2,370	6	0	Shell (9)
AISI 4140, bolts	175	–	402	2,370	6	3[b]	Shell (9)
AISI 4340 (150 ksi)	46	35	123	5,640	3	0	CEL (4)
AISI 4340 (150 ksi)	46	35	403	6,780	3	0	CEL (4)
AISI 4340 (150 ksi)	45	30	403	6,780	3	0	NADC (7)
AISI 4340 (150 ksi), Cd plated	45	30	403	6,780	3	0	NADC (7)
AISI 4340 (150 ksi), Ni plated	45	30	403	6,780	3	0	NADC (7)
AISI 4340 (150 ksi), Cu plated	45	30	403	6,780	3	0	NADC (7)
AISI 4340 (150 ksi)	46	35	751	5,640	3	0	CEL (4)
AISI 4340 (150 ksi)	45	30	751	5,640	3	0	NADC (7)
AISI 4340 (150 ksi)	46	35	197	2,340	3	0	CEL (4)
AISI 4340 (150 ksi)	45	30	197	2,340	3	0	NADC (7)
AISI 4340 (150 ksi)	45	30	403	2,370	3	0	NADC (7)
AISI 4340 (150 ksi), Cd plated	45	30	403	2,370	3	0	NADC (7)
AISI 4340 (150 ksi), Ni plated	45	30	403	2,370	3	0	NADC (7)
AISI 4340 (150 ksi), Cu plated	45	30	403	2,370	3	0	NADC (7)
AISI 4340 (150 ksi)	66	50	123	5,640	3	0	CEL (4)
AISI 4340 (150 ksi)	66	50	403	6,780	3	0	CEL (4)
AISI 4340 (150 ksi)	66	50	403	6,780	3	0	NADC (7)
AISI 4340 (150 ksi), Cd plated	66	50	403	6,780	3	0	NADC (7)
AISI 4340 (150 ksi), Ni plated	66	50	403	6,780	3	0	NADC (7)
AISI 4340 (150 ksi), Cu plated	66	50	403	6,780	3	0	NADC (7)
AISI 4340 (150 ksi)	66	50	751	5,640	3	0	CEL (4)
AISI 4340 (150 ksi)	66	50	751	5,640	3	0	NADC (7)
AISI 4340 (150 ksi)	66	50	197	2,340	3	0	CEL (4)

Continued

Table 7. Continued.

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed	Source[a]
AISI 4340 (150 ksi)	66	50	402	2,370	3	0	CEL (4)
AISI 4340 (150 ksi)	66	50	402	2,370	3	0	NADC (7)
AISI 4340 (150 ksi), Cd plated	66	50	402	2,370	3	0	NADC (7)
AISI 4340 (150 ksi), Ni plated	66	50	402	2,370	3	0	NADC (7)
AISI 4340 (150 ksi), Cu plated	66	50	402	2,370	3	0	NADC (7)
AISI 4340 (150 ksi)	99	75	123	5,640	3	0	CEL (4)
AISI 4340 (150 ksi)	99	75	403	6,780	3	0	CEL (4)
AISI 4340 (150 ksi)	99	75	403	6,780	3	0	NADC (7)
AISI 4340 (150 ksi), Cd plated	99	75	403	6,780	3	0	NADC (7)
AISI 4340 (150 ksi), Ni plated	99	75	403	6,780	3	0	NADC (7)
AISI 4340 (150 ksi), Cu plated	99	75	403	6,780	3	0	NADC (7)
AISI 4340 (150 ksi)	99	75	751	5,640	3	0	CEL (4)
AISI 4340 (150 ksi)	99	75	751	5,640	3	0	NADC (7)
AISI 4340 (150 ksi)	99	75	197	2,340	3	0	CEL (4)
AISI 4340 (150 ksi)	99	75	197	2,340	3	0	NADC (7)
AISI 4340 (150 ksi), Cd plated	99	75	197	2,340	3	0	NADC (7)
AISI 4340 (150 ksi), Ni plated	99	75	197	2,340	3	0	NADC (7)
AISI 4340 (150 ksi), Cu plated	99	75	197	2,340	3	0	NADC (7)
AISI 4340 (150 ksi)	99	75	402	2,370	3	0	CEL (4)
AISI 4340 (150 ksi)	99	75	402	2,370	3	0	NADC (7)
AISI 4340 (150 ksi), Cd plated	99	75	402	2,370	3	0	NADC (7)
AISI 4340 (150 ksi), Ni plated	99	75	402	2,370	3	0	NADC (7)
AISI 4340 (150 ksi), Cu plated	99	75	402	2,370	3	0	NADC (7)
AISI 4340 (200 ksi)	65	35	123	5,640	3	0	CEL (4)
AISI 4340 (200 ksi)	65	35	403	6,780	2	0	CEL (4)
AISI 4340 (200 ksi)	65	35	751	5,640	3	0	CEL (4)
AISI 4340 (200 ksi)	65	35	197	2,340	3	0	CEL (4)
AISI 4340 (200 ksi)	93	50	123	5,640	3	0	CEL (4)
AISI 4340 (200 ksi)	93	50	403	6,780	2	0	CEL (4)
AISI 4340 (200 ksi)	93	50	751	5,640	3	0	CEL (4)
AISI 4340 (200 ksi)	93	50	197	2,340	3	0	CEL (4)
AISI 4340 (200 ksi)	93	50	402	2,370	3	0	CEL (4)
AISI 4340 (200 ksi)	139	75	123	5,640	3	0	CEL (4)
AISI 4340 (200 ksi)	139	75	403	6,780	2	0	CEL (4)
AISI 4340 (200 ksi)	139	75	751	5,640	3	0	CEL (4)
AISI 4340 (200 ksi)	139	75	197	2,340	3	0	CEL (4)
AISI 4340 (200 ksi)	139	75	402	2,370	3	0	CEL (4)
ASTM A36	20	50	402	2,370	3	0	CEL (4)
ASTM A36	30	75	402	2,370	3	0	CEL (4)
ASTM A387-D	24	50	402	2,370	3	0	CEL (4)
ASTM A387-D	37	75	402	2,370	3	0	CEL (4)
HSLA No. 1[c]	38	35	197	2,340	3	0	CEL (4)
HSLA No. 1	55	50	197	2,340	3	0	CEL (4)
HSLA No. 1	55	50	402	2,370	3	0	CEL (4)
HSLA No. 1	82	75	197	2,340	3	0	CEL (4)
HSLA No. 1	82	75	402	2,370	3	0	CEL (4)
HSLA No. 4[d]	–	75	189	5,900	1	0	CEL (4)

Continued

Table 7. Continued.

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed	Source[a]
HSLA No. 4[e]	–	75	189	5,900	2	0	CEL (4)
HSLA No. 4[f]	–	75	189	5,900	1	0	CEL (4)
HSLA No. 5	41	35	197	2,340	3	0	CEL (4)
HSLA No. 5	59	50	197	2,340	3	0	CEL (4)
HSLA No. 5	59	50	402	2,370	3	0	CEL (4)
HSLA No. 5	89	75	197	2,340	3	0	CEL (4)
HSLA No. 5	89	75	402	2,370	3	0	CEL (4)
HSLA No. 5[d]	–	75	189	5,900	2	0	CEL (4)
HSLA No. 5[e]	–	75	189	5,900	2	0	CEL (4)
HSLA No. 5[f]	–	75	189	5,900	1	0	CEL (4)
HSLA No. 13[d]	–	75	189	5,900	2	0	CEL (4)
HSLA No. 13[e]	–	75	189	5,900	2	0	CEL (4)
HSLA No. 13[f]	–	75	189	5,900	1	0	CEL (4)
HS No. 3[g]	86	50	189	5,900	3	0	CEL (4)
HS No. 3[b]	86	50	189	5,900	3	0	CEL (4)
HS No. 3	129	75	189	5,900	3	0	CEL (4)
HS No. 3[b]	129	75	189	5,900	3	0	CEL (4)
HS No. 6	96	50	189	5,900	3	0	CEL (4)
HS No. 6[b]	96	50	189	5,900	3	0	CEL (4)
HS No. 6	143	75	189	5,900	3	0	CEL (4)
HS No. 6[b]	143	75	189	5,900	3	0	CEL (4)
HS No. 6[i]	96	50	189	5,900	3	0	CEL (4)
HS No. 6[b, i]	96	50	189	5,900	3	0	CEL (4)
HS No. 6[i]	143	75	189	5,900	3	0	CEL (4)
HS No. 6[b, i]	143	75	189	5,900	3	0	CEL (4)
AISI 502	18	50	197	2,340	3	0	CEL (4)
AISI 502	18	50	402	2,370	3	0	CEL (4)
AISI 502	27	75	197	2,340	3	0	CEL (4)
AISI 502	27	75	402	2,370	3	0	CEL (4)
18% Ni, maraging	83	33	123	5,640	3	0	NADC (7)
18% Ni, maraging	105	42	123	5,640	3	0	NADC (7)
18% Ni, maraging	158	50	189	5,900	3	0	CEL (4)
18% Ni, maraging[b]	158	50	189	5,900	3	2	CEL (4)
18% Ni, maraging	237	75	189	5,900	3	3	CEL (4)
18% Ni, maraging[b]	237	75	189	5,900	3	3	CEL (4)
18% Ni, maraging	–	75	403	6,780	3	3	NADC (7)
18% Ni, maraging[i, j]	–	75	403	6,780	3	3	NADC (7)
18% Ni, maraging	–	75	751	5,640	3	0	NADC (7)
18% Ni, maraging[i]	70	35	197	2,340	3	0	Boeing (6)
18% Ni, maraging[i]	100	50	197	2,340	3	0	Boeing (6)
18% Ni, maraging[i]	150	75	197	2,340	3	0	Boeing (6)
18% Ni, maraging	75	30	197	2,340	3	0	NADC (7)
18% Ni, maraging	125	50	197	2,340	3	0	NADC (7)
18% Ni, maraging	188	75	197	2,340	3	0	NADC (7)
18% Ni, maraging[i]	75	30	197	2,340	3	0	NADC (7)
18% Ni, maraging[i]	125	50	197	2,340	3	0	NADC (7)
18% Ni, maraging[i, j]	188	75	197	2,340	3	3	NADC (7)

Continued

Table 7. Continued.

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed	Source[a]
18% Ni, maraging, Cu plated[j]	188	75	197	2,340	3	0	NADC (7)
18% Ni, maraging, Ni plated[j]	188	75	197	2,340	3	0	NADC (7)
18% Ni, maraging	188	75	402	2,370	3	3	NADC (7)
18% Ni, maraging[j]	188	75	402	2,370	3	3	NADC (7)
18% Ni, maraging	109	35	402	2,370	3	0	CEL (4)
18% Ni, maraging	156	50	402	2,370	3	0	CEL (4)
18% Ni, maraging	234	75	402	2,370	3	0	CEL (4)
18% Ni, maraging[j]	109	35	402	2,370	3	0	CEL (4)
18% Ni, maraging[j]	156	50	402	2,370	3	0	CEL (4)
18% Ni, maraging[j]	234	75	402	2,370	3	0	CEL (4)
12% Ni, maraging	63	35	197	2,340	3	0	Boeing (6)
12% Ni, maraging	90	50	197	2,340	3	0	Boeing (6)
12% Ni, maraging	135	75	197	2,340	3	0	Boeing (6)

[a]Numbers refer to references at end of report.

[b]One specimen failed in bottom sediment, two in water.

[c]HSLA = high-strength, low-alloy steel.

[d]Zinc-rich primer, 8 mils.

[e]Zinc-rich primer, 8 mils plus wash primer (MIL-C-8514), 6 mils plus epoxy topcoat, 6 mils.

[f]Epoxy tar primer, 8 mils plus epoxy topcoat, 8 mils.

[g]HS = high-strength steel.

[h]Exposed in bottom sediment.

[i]TIG welded.

[j]Cracked at edge of heat affected zone.

Table 8. Changes in Mechanical Properties of Irons and Steels Due to Corrosion

Alloy	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[a]
			Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
Wrought iron	123	5,640	47	–	30	–	15	–	CEL (4)
Wrought iron	403	6,780	47	+5	30	+2	15	+118	CEL (4)
Wrought iron	751	5,640	47	+6	30	0	15	+154	CEL (4)
Wrought iron	1,064	5,300	47	+6	30	+3	15	+113	CEL (4)
Wrought iron	197	2,340	47	–	30	–	15	–	CEL (4)
Wrought iron	402	2,370	47	+2	30	-25	15	+26	CEL (4)
Wrought iron	181	5	47	+7	30	-8	15	+17	CEL (4)
AISI 1010	123	5,640	54	-1	36	0	42	+1	CEL (4)
AISI 1010	403	6,780	54	+1	36	+6	42	-8	CEL (4)
AISI 1010	751	5,640	54	0	36	+3	42	-3	CEL (4)
AISI 1010	1,064	5,300	54	+6	36	+8	42	-5	CEL (4)
AISI 1010	197	2,340	54	+2	36	+4	42	-4	CEL (4)
AISI 1010	402	2,370	54	-2	36	-4	42	-3	CEL (4)
AISI 1010	181	5	54	+3	36	-1	42	-18	CEL (4)
ASTM A36	123	5,640	66	-1	39	+2	39	+9	CEL (4)
ASTM A36	403	6,780	66	+2	39	+4	39	-11	CEL (4)
ASTM A36	751	5,640	66	+1	39	+6	39	-11	CEL (4)
ASTM A36	1,064	5,300	66	+4	39	+4	39	+14	CEL (4)
ASTM A36	197	2,340	66	+2	39	+4	39	-1	CEL (4)
ASTM A36	402	2,370	66	+1	39	-2	39	-4	CEL (4)
ASTM A36	181	5	66	+1	39	-1	39	-19	CEL (4)
ASTM A387-D	123	5,640	76	+3	49	+4	32	-5	CEL (4)
ASTM A387-D	403	6,780	76	+6	49	+6	32	-16	CEL (4)
ASTM A387-D	751	5,640	76	+7	49	+7	32	-17	CEL (4)
ASTM A387-D	1,064	5,300	76	–	49	–	32	–	CEL (4)
ASTM A387-D	197	2,340	76	+4	49	-2	32	-10	CEL (4)
ASTM A387-D	402	2,370	76	+3	49	+6	32	-10	CEL (4)
HSLA No. 1[b]	123	5,640	121	0	110	+1	12	+42	CEL (4)
HSLA No. 1	403	6,780	121	+3	110	+3	12	+32	CEL (4)
HSLA No. 1	751	5,640	121	+2	110	+4	12	+31	CEL (4)
HSLA No. 1	1,064	5,300	121	+2	110	+3	12	+32	CEL (4)
HSLA No. 1	197	2,340	121	+2	110	+2	12	+39	CEL (4)
HSLA No. 1	402	2,370	121	+1	110	-1	12	+30	CEL (4)
HSLA No. 1	181	5	121	+1	110	+1	12	+13	CEL (4)

Continued

Table 8. Continued.

Alloy	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[a]
			Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
HSLA No. 2	123	5,640	100	+1	89	−2	28	−12	CEL (4)
HSLA No. 2	403	6,780	100	+4	89	−2	28	−12	CEL (4)
HSLA No. 2	751	5,640	100	+6	89	+4	28	−3	CEL (4)
HSLA No. 2	1,064	5,300	100	+6	89	+4	28	+42	CEL (4)
HSLA No. 2	197	2,340	100	+4	89	+2	28	−9	CEL (4)
HSLA No. 2	402	2,370	100	+2	89	−3	28	−11	CEL (4)
HSLA No. 2	181	5	100	+1	89	+3	28	0	CEL (4)
HSLA No. 3	1,064	5,300	107	+10	88	+4	30	+33	CEL (4)
HSLA No. 4	123	5,640	70	+5	52	+7	32	+24	CEL (4)
HSLA No. 4	403	6,780	70	+4	52	+4	32	+40	CEL (4)
HSLA No. 4	751	5,640	70	+4	52	+7	32	+18	CEL (4)
HSLA No. 4	1,064	5,300	70	+5	52	+6	32	+20	CEL (4)
HSLA No. 4	197	2,340	70	+6	52	+8	32	+36	CEL (4)
HSLA No. 4	402	2,370	70	+3	52	−2	32	−33	CEL (4)
HSLA No. 5	123	5,640	125	+1	118	+2	16	−1	CEL (4)
HSLA No. 5	403	6,780	125	+4	118	+5	16	−11	CEL (4)
HSLA No. 5	751	5,640	125	+6	118	+5	16	−6	CEL (4)
HSLA No. 5	1,064	5,300	125	+6	118	+6	16	−2	CEL (4)
HSLA No. 5	197	2,340	125	+2	118	+2	16	+2	CEL (4)
HSLA No. 5	197	2,340	105	0	123	0	17	−2	NADC (7)
HSLA No. 5	402	2,370	125	+3	118	+4	16	−3	CEL (4)
HSLA No. 5	402	2,370	123	0	105	+12	17	−2	NADC (7)
HSLA No. 5[c]	402	2,370	123	−1	105	0	17	−77	NADC (7)
HSLA No. 5[d]	402	2,370	123	+7	105	+13	17	−82	NADC (7)
HSLA No. 5[e]	402	2,370	123	+3	105	+17	17	−4	NADC (7)
HSLA No. 5[f]	402	2,370	123	−1	105	+10	17	−2	NADC (7)
HSLA No. 5[g]	402	2,370	123	−5	105	+4	17	−29	NADC (7)
HSLA No. 6	402	2,370	131	+2	117	−1	16	−10	CEL (4)
HSLA No. 12	181	5	120	0	109	−2	26	+4	CEL (4)
HS No. 1[b]	181	5	145	−2	140	−3	22	+7	CEL (4)
HS No. 2	181	5	194	−4	186	−5	15	+5	CEL (4)
HS No. 3	402	2,370	169	0	118	−6	14	+8	CEL (4)

Continued

Table 8. Continued.

Alloy	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[a]
			Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
AISI 4130	123	5,640	91	-22	63	-30	30	-13	NADC (7)
AISI 4130	123	5,640	169	-44	–	–	11	0	NADC (7)
AISI 4130	403	6,780	169	0	148	-7	11	-41	NADC (7)
AISI 4130	751	5,640	91	-23	63	-34	30	-22	NADC (7)
AISI 4130	1,064	5,300	91	-27	63	-37	–	-31	NADC (7)
AISI 4130	197	2,340	91	0	63	0	30	-11	NADC (7)
AISI 4130	402	2,370	169	+7	148	-35	11	-41	NADC (7)
AISI 4130	402	2,370	91	-3	63	+43	30	-36	NADC (7)
AISI 4130[e]	402	2,370	91	-17	63	-21	30	-14	NADC (7)
AISI 4130[f]	402	2,370	91	-17	63	-23	30	-26	NADC (7)
AISI 4130[g]	402	2,370	91	-17	63	+6	–	–	NADC (7)
AISI 4340	123	5,640	201	+4	185	+5	8	+43	CEL (4)
AISI 4340	123	5,640	143	+3	132	+4	13	+28	CEL (4)
AISI 4340	402	6,780	201	+4	185	+3	8	+25	CEL (4)
AISI 4340	402	6,780	209	+1	190	+1	8	-2	CEL (4)
AISI 4340	402	6,780	143	-1	132	-3	13	+27	CEL (4)
AISI 4340	402	6,780	147	0	136	-1	14	-6	CEL (4)
AISI 4340	751	5,640	201	+3	185	+10	8	+30	CEL (4)
AISI 4340	751	5,640	143	+3	132	+3	13	+28	CEL (4)
AISI 4340	197	2,340	201	+3	185	+5	8	+49	CEL (4)
AISI 4340	197	2,340	209	-2	190	-1	8	+11	CEL (4)
AISI 4340	197	2,340	143	+5	132	+4	13	+29	CEL (4)
AISI 4340	197	2,340	147	0	136	0	14	-3	CEL (4)
AISI 4340	197	2,340	293	-37	213	-19	9	0	NADC (7)
AISI 4340	402	2,370	209	-2	190	0	8	+3	CEL (4)
AISI 4340	402	2,370	147	-2	136	-3	14	-5	CEL (4)
AISI 4340	402	2,370	200	+1	184	+1	9	–	NADC (7)
AISI 4340[e]	402	2,370	200	-18	184	-14	9	-27	NADC (7)
AISI 4340[f]	402	2,370	200	-29	184	–	9	-48	NADC (7)
AISI 4340[g]	402	2,370	200	-40	184	–	9	-73	NADC (7)
AISI 502	123	5,640	59	-2	36	+5	33	-34	CEL (4)
AISI 502	403	6,780	59	-5	36	+1	33	-17	CEL (4)
AISI 502	751	5,640	59	-8	36	+6	33	-38	CEL (4)
AISI 502	1,064	5,300	59	-3	36	+3	33	-38	CEL (4)
AISI 502	197	2,340	59	-1	36	-4	33	-2	CEL (4)

Continued

Table 8. Continued.

Alloy	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[a]
			Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
AISI 502	402	2,370	59	-1	36	+4	33	-13	CEL (4)
AISI 502	181	5	59	+5	36	0	33	-29	CEL (4)
18 Ni, maraging	123	5,640	245	-38	–	–	5	+122	NADC (7)
18 Ni, maraging	1,064	5,300	245	+8	241	+8	5	-31	NADC (7)
18 Ni, maraging	197	2,340	245	-24	241	-24	5	-2	NADC (7)
18 Ni, maraging	402	2,370	245	-13	241	-15	5	-64	NADC (7)
18 Ni, maraging	402	2,370	321	-6	315	–	3	-16	CEL (4)
18 Ni, maraging[i]	402	2,370	170	-6	151	-1	8	-51	CEL (4)
18 Ni, maraging[j]	402	2,370	254	+6	236	+2	7	+16	CEL (4)
18 Ni, maraging[k]	402	2,370	252	+7	239	+8	7	+4	CEL (4)
Austenitic cast iron, Type 4	402	2,370	23	-4	20	-8	2	-35	CEL (4)
Austenitic cast iron, Type 4	181	5	23	+11	20	+7	2	+30	CEL (4)
Austenitic cast iron, Type D-2C	402	2,370	47	-38	42	-56	5	-36	CEL (4)
Austenitic cast iron, Type D-2C	181	5	47	-18	42	-8	5	-34	CEL (4)
Galvanized steel, 1 oz/ft^2	402	2,370	49	+3	40	0	38	-6	CEL (4)
Aluminized steel, 1 oz/ft^2	402	2,370	51	-2	38	-7	28	+3	CEL (4)

[a]Numbers refer to references at end of report.

[b]HSLA = high-strength, low-alloy steel.

[c]1/4-in. thick.

[d]1/8-in. thick.

[e]Cadmium plated.

[f]Copper plated.

[g]Nickel plated.

[h]HS = high-strength steel.

[i]Welded.

[j]Machined, RMS 125.

[k]As rolled.

Table 9. Effect of Corrosion on Breaking Strengths of Anchor Chains

(chains degreased, 0.75-inch size)

Designation	Exposure		Breaking Load (lb)		Remarks
	Days	Depth	Original	Final	
Dilok	123	5,640	59,000	58,500	Thin film flaky rust, broke at bottom of socket
Dilok	403	6,780	59,000	64,500	Thin film flaky rust, broke at bottom of socket
Dilok	751	5,640	59,000	71,000	Thin film flaky rust, broke at bottom of socket
Dilok	197	2,340	59,000	76,500	Thin film flaky rust, broke at end of link
Welded stud link	123	5,640	57,500	61,500	Thin film flaky rust, broke at end of link
Welded stud link	403	6,780	57,500	59,500	Thin film flaky rust, broke at end of link
Welded stud link	751	5,640	57,500	59,500	Thin film flaky rust, broke at end of link
Welded stud link	197	2,340	57,500	61,000	Thin film flaky rust, broke at end of link

SECTION 3

COPPER ALLOYS

The excellent corrosion resistance of copper and its alloys is partially due to its being a relatively noble metal. However, in many environments, its satisfactory performance depends on the formation of adherent, relatively thin films of corrosion products. In seawater corrosion, resistance depends on the presence of a surface oxide film through which oxygen must diffuse in order for corrosion to continue. This oxide film adjoining the metal is cuprous oxide covered with a mixture of cupric oxy-chloride, cupric hydroxide, basic cupric carbonate, and calcium sulfate. Since oxygen must diffuse through this film for corrosion to occur, it would be expected that under normal circumstances the corrosion rates would decrease with increase in time of exposure.

Copper alloys corrode uniformly; hence, corrosion rates calculated from weight losses and reported as mils per year reflect the true condition of the alloys. Therefore, corrosion rates for the copper alloys can be used reliably for design purposes. However, this does not apply to those copper base alloys which are susceptible to parting corrosion. (Parting corrosion is defined as the selective attack of one or more of the components of a solid solution alloy.) Examples of parting corrosion are dezincification, dealuminification, denickelification, desiliconification, etc.

The data on the copper alloys were obtained from the reports given in References 3 through 19 and 23. The copper alloys are separated into the different classes of copper alloys (coppers, brasses, bronzes, and copper-nickel alloys) for comparison and discussion purposes.

The chemical compositions, corrosion rates and types of corrosion, stress corrosion characteristics, and changes in mechanical properties due to corrosion of the coppers are given in Tables 10 through 13. The effects of duration of exposure are shown graphically in Figures 8 and 15.

The chemical compositions, corrosion rates and types of corrosion, stress corrosion characteristics, and changes in mechanical properties due to the corrosion of the brasses are given in Tables 14 through 17. The effects of the duration of exposure are shown graphically in Figures 11 and 15.

The chemical compositions, corrosion rates and types of corrosion, stress corrosion characteristics, and changes in mechanical properties due to corrosion of the bronzes are given in Tables 18 through 21. The effects of the duration of exposure are shown graphically in Figures 12 and 15.

The chemical compositions, corrosion rates and types of corrosion, stress corrosion characteristics, and changes in mechanical properties due to corrosion of the copper-nickel alloys are given in Tables 22 through 25. The effects of the duration of exposure are shown graphically in Figures 13 and 15.

The effects of depth and the effect of the concentration of oxygen in seawater on the corrosion of the copper alloys are shown in Figures 9 and 14.

The effect of the iron content on the corrosion of the copper-nickel alloys is shown in Figure 14.

3.1. COPPERS

The chemical compositions of the coppers are given in Table 10, their corrosion rates and types of corrosion in Table 11, their resistance to stress corrosion cracking in Table 12, and the changes in their mechanical properties due to corrosion in Table 13.

3.1.1. Duration of Exposure

The effects of the duration of exposure on the corrosion of copper in seawater at depth, at the surface, and in the bottom sediments are shown graphically in Figure 8. At the surface and at the 6,000-foot depth, both in the seawater and in the bottom sediment, the corrosion rates decreased with increasing duration of exposure. At the 2,500-foot depth the corrosion rates in the seawater and in the bottom sediment were essentially constant. Also, the corrosion rates were practically the same at depth as at the surface.

The beryllium-copper alloys behaved very similarly to copper, and their corrosion rates were comparable. Beryllium-copper chain corroded at the same rates and in the same manner as the alloy in sheet form. Welding by either the TIG or MIG processes as well as aging at either 600°F or 800°F did not affect the corrosion behavior of the beryllium-copper alloys.

3.1.2. Effect of Depth

The effect of depth on the corrosion of copper is shown in Figure 9. The corrosion of copper was not affected by depth, at least to a depth of 6,000 feet.

3.1.3. Effect of Concentration of Oxygen

The effect of the concentration of oxygen in seawater on the corrosion of copper is shown in Figure 10. The corrosion of copper was unaffected by the concentration of oxygen in seawater within the range of 0.4 to 5.75 ppm.

3.1.4. Stress Corrosion

Copper and beryllium-coppers were exposed in the seawater while stressed at values equivalent to 30 and 75% of their respective yield strengths for the periods of time and at the depths shown in Table 12. Neither copper nor the beryllium-coppers were susceptible to stress corrosion. Aging at either 600°F or 800°F did not affect the stress corrosion resistance of beryllium-copper (CDA No. 172).

3.1.5. Mechanical Properties

The effects of exposure in seawater on their mechanical properties are given in Table 13. The mechanical properties of the copper and the beryllium-coppers were not significantly affected by exposure in seawater at the surface or at depth.

3.1.6. Galvanic Corrosion

Dissimilar metal couples consisting of 1 x 2-inch strips of aluminum alloy 7075-T6 fastened to 1 x 6-inch strips of beryllium-copper alloy (CDA No. 175) with plastic fasteners were exposed in seawater at a depth of 2,500 feet for 402 days. After exposure the 7075-T6 was covered with a heavy uniform layer of corrosion products, while there was a thin layer of corrosion products on the CDA No. 175 alloy. This indicates that the aluminum was corroding galvanically to protect the beryllium-copper from corroding.

3.2. BRASSES (Copper-Zinc Alloys)

The chemical compositions of the brasses are given in Table 14, their corrosion rates and types of corrosion in Table 15, their resistance to stress corrosion cracking in Table 16, and the changes in their mechanical properties due to corrosion in Table 17.

3.2.1. Duration of Exposure

The effects of the duration of exposure on the corrosion of the brasses in seawater at depth, at the surface, and in the bottom sediments are shown in Figure 11.

Since the corrosion rates of all the brasses, except those of alloys, CDA No. 280 and 675, were so comparable, the average values for any one time, depth, or environment were used to prepare the curves in Figure 11. The corrosion rate values of alloys CDA No. 280 (Muntz Metal) and CDA No. 675 (manganese bronze A) were considerably higher than those of all the other brasses. These high rates were attributed to the severe parting corrosion (dezincification) which had occurred on these two alloys.

The curves in Figure 11 show the effects of the duration of exposure on the corrosion of the brasses in seawater. The corrosion rates of the brasses decreased slightly with increasing duration of exposure at the surface and at depths of 2,500 and 6,000 feet both in seawater and in the bottom sediments. The corrosion of the brasses was the same in the bottom sediments as in the seawater at the 6,000-foot depth, but slower in the bottom sediments than in the seawater at the 2,500-foot depth. The corrosion in seawater was practically the same at the 2,500-foot depth as at the 6,000-foot depth. The brasses corroded slightly slower at depth than at the surface.

3.2.2. Parting Corrosion (Dezincification)

The alloys attacked by parting corrosion are shown in Table 15. All the brasses, except Arsenical

Admiralty (CDA No. 443), aluminum brass, and nickel brass, were attacked by parting corrosion in degrees varying from slight to severe. The zinc content varied from 10 to 42% with the severity of parting corrosion generally increasing with the zinc content. Although the Arsenical Admiralty contained about 30% zinc, the addition of about 0.03% arsenic rendered it immune to parting corrosion. Because of the 2% aluminum in aluminum brass and the 8% nickel in the nickel brass, they were also immune to parting corrosion even though they contained 20 and 40% zinc, respectively.

3.2.3. Effect of Depth

The effect of depth on the corrosion of the brasses after 1 year of exposure in seawater is shown in Figure 9. Although there was a slight tendency for the brasses to corrode more slowly at depth than at the surface, this slight decrease is not significant.

3.2.4. Effect of Concentration of Oxygen

The effect of the concentration of oxygen in seawater on the corrosion of the brasses after 1 year of exposure is shown in Figure 10. The corrosion of the brasses increased linearly, but slightly, with increasing oxygen concentration.

3.2.5. Stress Corrosion

Two brasses, CDA No. 280 and 443, were exposed in seawater while stressed at values equivalent to 50 and 75% of their respective yield strengths for the periods of time and at the depths given in Table 16. Neither alloy was susceptible to stress corrosion at either depth, 2,500 or 6,000 feet, after 400 days of exposure.

3.2.6. Mechanical Properties

The effects of corrosion on the mechanical properties of three brasses are given in Table 17. The mechanical properties of Arsenical Admiralty were not impaired, while those of Muntz Metal and nickel-manganese bronze were impaired. The degree of impairment increased with the time of exposure at both depths, 2,500 and 6,000 feet. The degree of impairment in both alloys roughly paralleled the severity of the parting corrosion.

3.2.7. Corrosion Products

The corrosion products which formed on cast nickel-manganese bronze during 403 days of exposure at a depth of 6,000 feet were analyzed by X-ray diffraction, spectrographic, infra-red spectrophotometer, and quantitative analyses methods. The corrosion products were composed of cupric chloride ($CuCl_2 \cdot 2H_2O$); copper hydroxychloride ($Cu_2(OH)_3Cl$); copper as metal, 35.98%; minor amounts of aluminum, iron, silicon, and sodium; chloride ions as Cl, 0.91%; sulfate ions as SO_4, 11.53%; small quantities of an organic compound or compounds present due to decomposed algae and vegetative materials.

3.3. BRONZES

The chemical compositions of the bronzes are given in Table 18, their corrosion rates and types of corrosion in Table 19, their resistance to stress corrosion in Table 20, and the changes in their mechanical properties due to corrosion in Table 21.

3.3.1. Duration of Exposure

The effects of the duration of exposure on the corrosion of the bronzes in seawater at depths, at the surface, and in the bottom sediments are shown in Figure 12.

Since the corrosion rates of all the bronzes, except those of alloys CDA No. 653 and 655 (silicon bronzes), were so comparable, the average values for any one time, depth, or environment were used to prepare the curves in Figure 12. Because the corrosion rates of the silicon bronzes were so much greater than those of the other bronzes, they were not averaged with the others. They are shown in Figure 12 as a separate curve that includes the rates for both depths as well as those for the surface. The average corrosion of the bronzes in seawater and in the bottom sediments was essentially constant with increasing duration of exposure. Also, it was essentially the same at the 2,500-foot depth as at the

6,000-foot depth, both in the seawater and in the bottom sediments. The corrosion of the silicon bronzes was greater than that of the other bronzes at depth and at the surface; it decreased with increasing duration of exposure until it was the same as the other bronzes after 1,064 days of exposure. The average corrosion of the bronzes in surface seawater was greater than at depth, and it decreased with increasing duration of exposure.

3.3.2. Parting Corrosion

Parting corrosion was found on all the aluminum bronzes (dealuminification) and on the silicon bronzes (coppering) as shown in Table 19. The parting corrosion was most severe on the cast alloy containing 10, 11, and 13% aluminum. There was much less on the wrought aluminum bronzes with there being very few cases of slight attack on the alloy containing 5% aluminum and more cases on the alloy containing 7% aluminum. The parting corrosion on the silicon bronzes occurred only occasionally, but its rating varied from slight to severe.

3.3.3. Effect of Depth

The effect of depth on the corrosion of the bronzes after 1 year of exposure in seawater is shown in Figure 9. The bronzes corroded slightly slower at depth than at the surface, but the difference was not considered to be significant. For practical purposes depth does not influence the corrosion of the bronzes.

3.3.4. Effect of Concentration of Oxygen

The effect of the concentration of oxygen in seawater on the corrosion of the bronzes after 1 year of exposure is shown in Figure 10. The corrosion of the bronzes increased linearly, but slightly, with increasing oxygen concentration, and at 5.75 ml/l oxygen they were corroding at the same rate as copper and other copper alloys.

3.3.5. Stress Corrosion

Four bronzes, phosphor bronze A, phosphor bronze D, aluminum bronze 5%, and silicon bronze A, were exposed in seawater to determine their susceptibility to stress corrosion. They were stressed at values equivalent to 35, 50, and 75% of their respective yield strengths as shown in Table 20. They were not susceptible to stress corrosion for periods of exposure of 400 days at either depth.

3.3.6. Mechanical Properties

The effects of corrosion on the mechanical properties of four bronzes are given in Table 21. The mechanical properties of the phosphor bronzes A and D were not affected by exposures at depth. The decreases (12, 27, and 29%) in the elongation of the aluminum bronze were attributed to parting corrosion. Also, the decrease in the mechanical properties of silicon bronze A after 403 days of exposure in the bottom sediments at a depth of 6,000 feet was attributed to parting corrosion.

3.3.7. Corrosion Products

Chemical analyses of the corrosion products removed from aluminum bronze showed the presence of copper oxy-chloride, cupric chloride; major elements, copper and aluminum; minor elements, iron, magnesium, calcium, and silicon; chloride ion, 0.9%, and sulfate ion, 9.0%.

3.4. COPPER-NICKEL ALLOYS

The chemical compositions of the copper-nickel alloys are given in Table 22, their corrosion rates and type of corrosion in Table 23, their resistance to stress corrosion in Table 24, and the changes in their mechanical properties due to corrosion in Table 25.

3.4.1. Duration of Exposure

The effects of the duration of exposure on the corrosion of the copper-nickel alloys in seawater at depths, at the surface, and in the bottom sediments are shown in Figure 13.

Because the corrosion rates of all the copper-nickel alloys were comparable, average values for any one time, depth, or environment were used to construct the curves in Figure 13. The average corrosion at the surface and at the 6,000-foot depth, both in seawater and in the bottom sediments, decreased linearly with increasing duration of exposure, while corrosion attack was constant in seawater and in the bottom sediments with increasing duration of exposure at the 2,500-foot depth. Corrosion at the 2,500-foot depth was slightly less rapid than at the surface or the 6,000-foot depth. Corrosion in surface seawater decreased at a more rapid rate than at depth. The differences in the corrosion rates of the copper-nickel alloys in the different environments were so small that, for practical purposes, they can be considered to be the same.

3.4.2. Effect of Depth

The effect of depth on the corrosion of the copper-nickel alloys after 1 year of exposure in seawater is shown in Figure 9. Depth exerted no influence on the corrosion of the copper-nickel alloys during 1 year of exposure, at least to a depth of 6,000 feet.

3.4.3. Effect of Concentration of Oxygen

The effect of the concentration of oxygen in seawater on the corrosion of the copper-nickel alloys after 1 year of exposure is shown in Figure 10. The corrosion increased slightly with increasing oxygen concentration during 1 year of exposure.

3.4.4. Effect of Iron

Copper-nickel alloys with iron contents varying between 0.03 and 5% were among the alloys in this program. The effects of iron on the corrosion of these alloys after 400 days and 1,064 days of exposure at the 6,000-foot depth are shown in Figure 14. Generally, the rates of corrosion decreased with increasing iron content.

3.4.5. Stress Corrosion

Four copper-nickel alloys were exposed in seawater to determine their susceptibility to stress corrosion under the conditions given in Table 24. They were not susceptible to stress corrosion.

3.4.6. Mechanical Properties

The effects of corrosion on the mechanical properties of five copper-nickel alloys are given in Table 25. The mechanical properties were not adversely affected during exposure at the depths and during the times of exposure given in Table 25.

3.4.7. Corrosion Products

Chemical analyses of the corrosion products removed from 70% copper-30% nickel-5% iron exposed for 751 days at a depth of 6,000 feet showed that they were composed of nickel hydroxide ($Ni(OH)_2$); cupric chloride ($CuCl_2$); major elements, copper and nickel; minor elements, iron, magnesiun, sodium, and traces of silicon, and manganese; chloride ion as Cl, 4.77%; sulfate ions as SO_4, 0.80%; copper as metal, 43.63%.

3.5. ALL COPPER ALLOYS

The effects of the duration of exposure on the corrosion of all the copper alloys in seawater at the surface and at the 6,000-foot depth are summarized in Figure 15. Their rates of corrosion decreased essentially linearly with increasing duration of exposure. Their rates were also comparable and were essentially the same after 1,064 days of exposure.

The corrosion of all the copper alloys was not affected by depth as shown in Figure 9.

The corrosion of copper and the silicon bronzes was not influenced by changes in the concentration of oxygen in seawater during 1 year of exposure, while that of the other alloys increased with increasing oxygen concentration, as shown in Figure 10.

None of the copper alloys were susceptible to stress corrosion.

The mechanical properties of copper, the beryllium-copper alloys, copper-nickel alloys, phosphor bronzes A and D, and Arsenical Admiralty brass were not adversely affected by exposure in seawater either at the surface or at depth. Those of 5% aluminum bronze, silicon bronze A, Muntz Metal, and nickel-manganese bronze were adversely affected.

Aluminum alloy 7075-T6 was galvanically corroded when in contact with beryllium-copper.

All the brasses containing from 10 to 42% zinc, except Arsenical Admiralty, aluminum brass, nickel brass, all the aluminum bronzes, and the silicon bronzes, were attacked by parting corrosion.

Corrosion products consisted of cupric chloride ($CuCl_2 \cdot H_2O$), copper oxychloride ($Cu_2(OH_3Cl)$), nickel hydroxide ($Ni(OH)_2$), copper, aluminum, nickel, iron, silicon, sodium, magnesium, manganese, calcium, chloride ion, and sulfate ion.

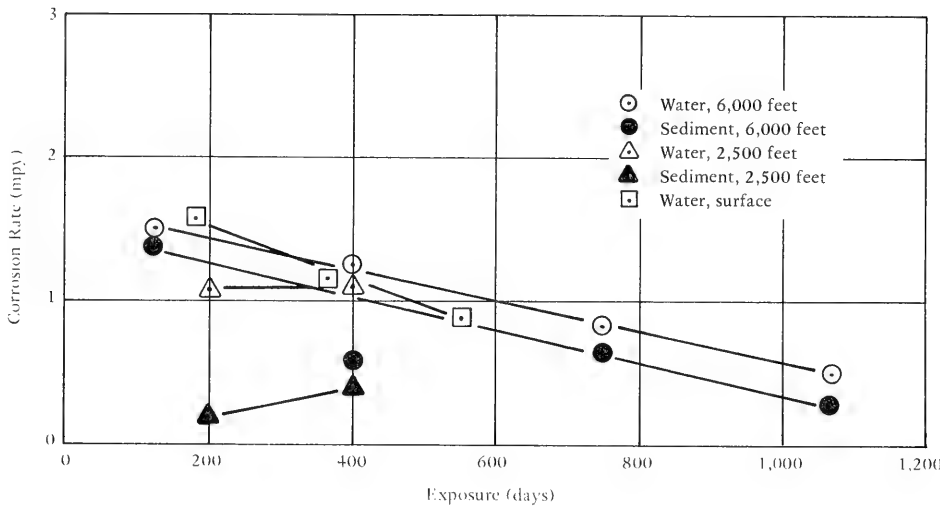

Figure 8. Effect of the duration of exposure on the corrosion of copper in seawater.

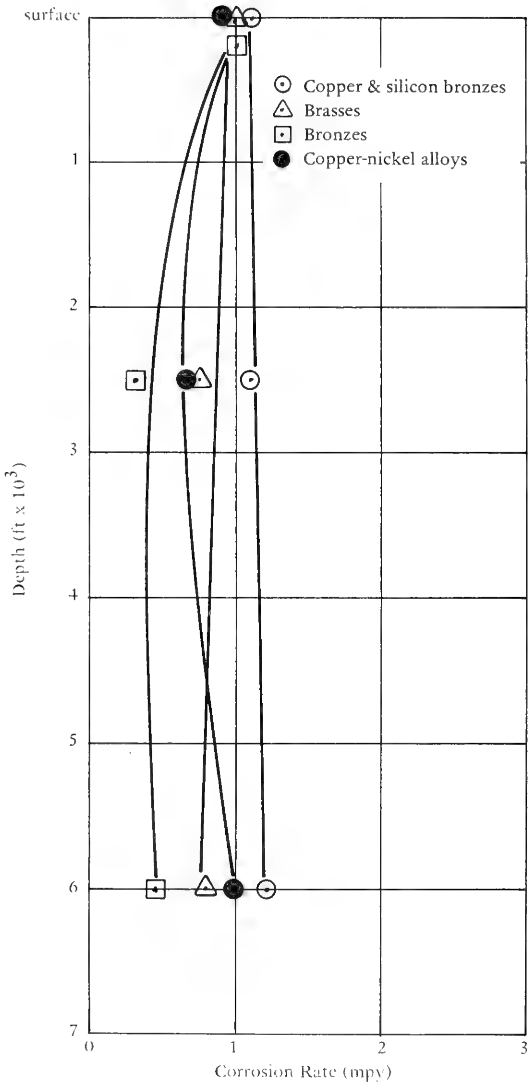

Figure 9. Effect of depth on the corrosion of copper alloys after 1 year of exposure in seawater.

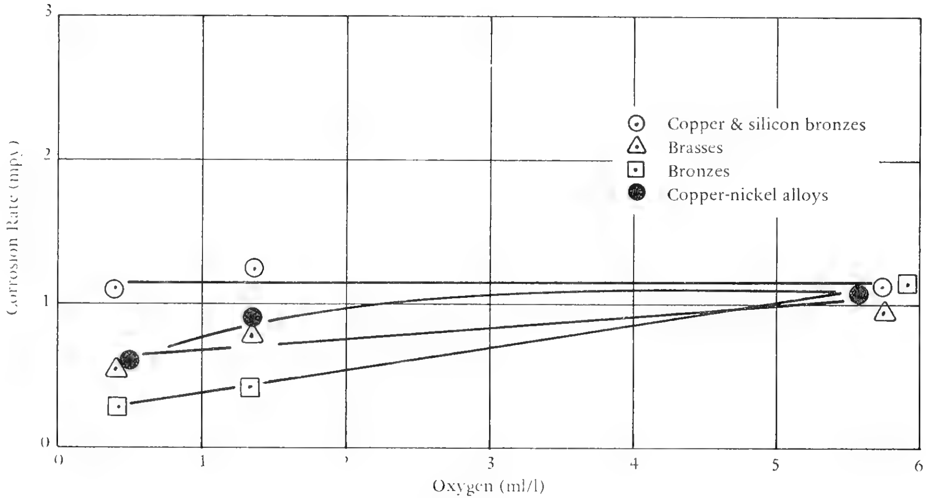

Figure 10. Effect of concentration of oxygen in seawater on the corrosion of copper alloys after 1 year of exposure.

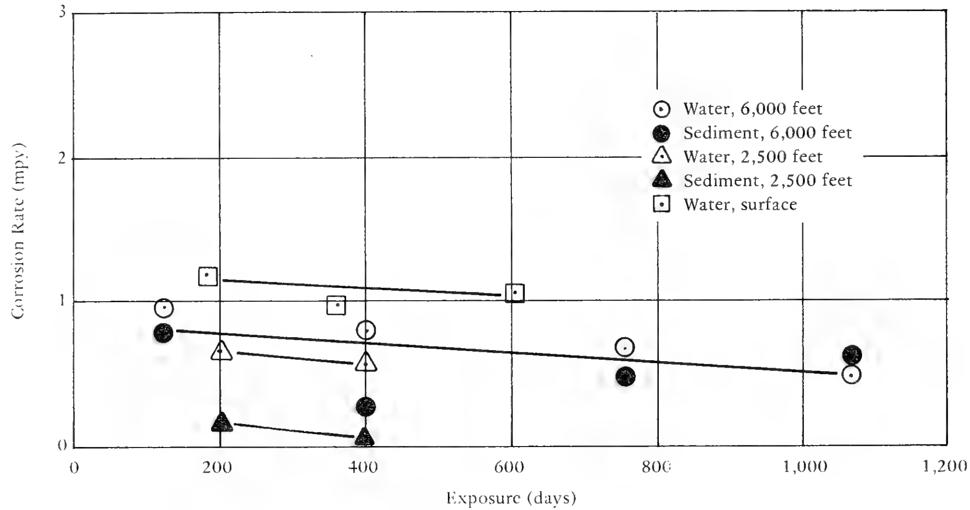

Figure 11. Effect of duration of exposure on the corrosion of brasses in seawater.

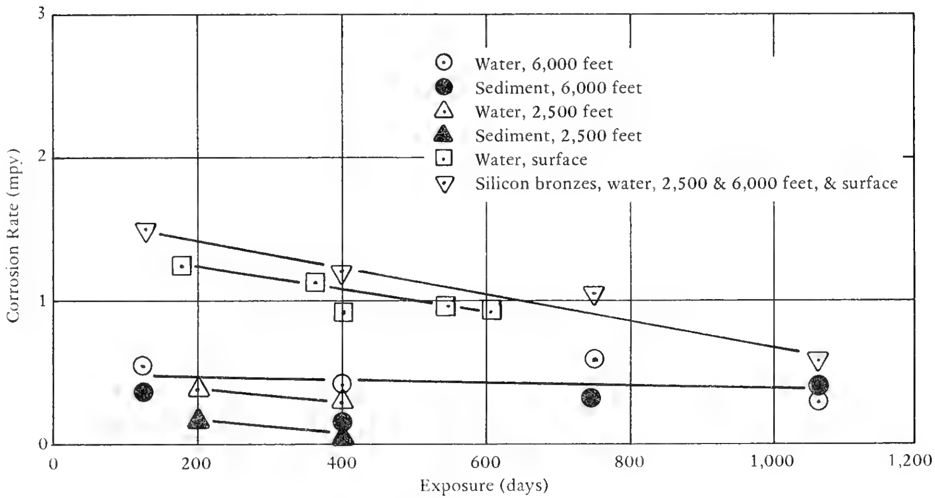

Figure 12. Effect of duration of exposure on the corrosion of bronzes in seawater.

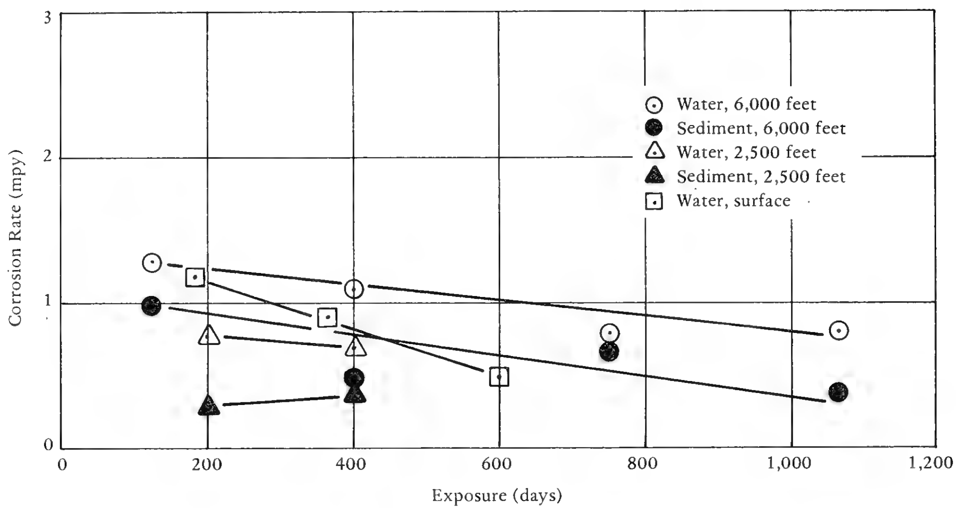

Figure 13. Effect of duration of exposure on the corrosion of copper-nickel alloys in seawater.

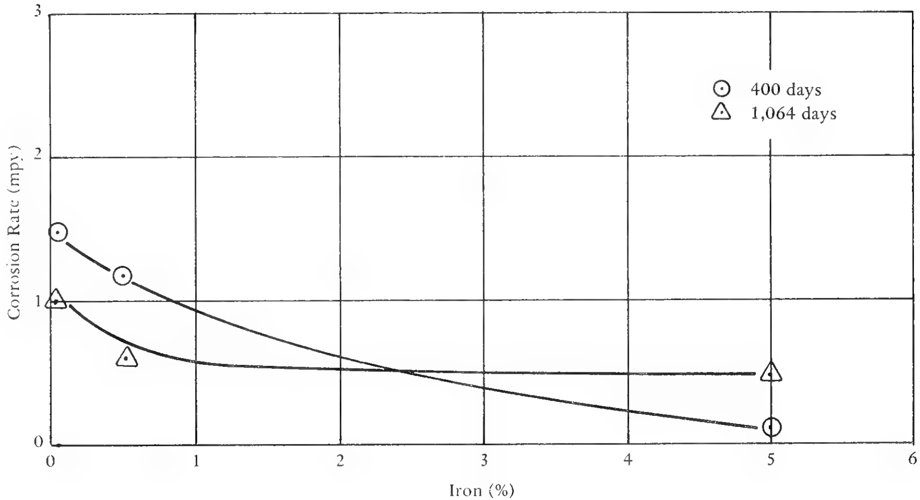

Figure 14. Effect of concentration of iron on the corrosion of the copper-nickel alloys in seawater at the 6,000-foot depth.

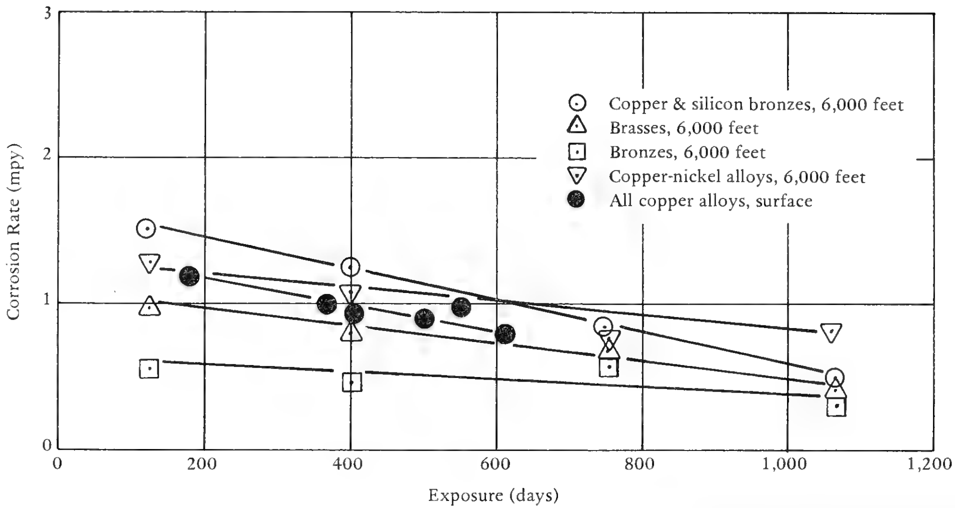

Figure 15. Effect of duration of exposure on the corrosion of copper alloys in seawater.

Table 10. Chemical Composition of Coppers, Percent by Weight

Alloy	CDA No.[a]	Cu	Ni	Be	Co	Source[b]
Copper, O free	102	99.96	–	–	–	CEL (4)
Copper, O free	102	99.9	–	–	–	INCO (3)
Copper, O free	102	99.97	–	–	–	CEL (4)
Copper, O free	102	99.9	–	–	–	MEL (5)
Be-Cu	170	97.06	–	2.02	0.58	NADC (7)
Be-Cu	172	97.42	–	2.02	0.54	NADC (7)
Be-Cu	172	97.80	0.05	1.90	0.25	CEL (4)
Be-Cu	175	97.06	–	0.61	2.4	NADC (7)
Be-Cu chain[c]	825	remainder	–	2.0	0.5	CEL (4)

[a]Copper Development Association alloy number.

[b]Numbers refer to references at end of report.

[c]Cast alloy.

Table 11. Corrosion Rates and Types of Corrosion of Coppers

Alloy	CDA No.[a]	Environment[b]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Type of Corrosion[c]	Source[d]
Copper, O free	102	W	123	5,640	1.6	U	CEL (4)
Copper, O free	102	W	123	5,640	1.5	U	INCO (3)
Copper, O free	102	S	123	5,640	1.3	U	CEL (4)
Copper, O free	102	S	123	5,640	1.5	U	INCO (3)
Copper, O free	102	W	123	5,640	1.9	U	MEL (5)
Copper, O free	102	W	403	6,780	1.2	U	CEL (4)
Copper, O free	102	W	403	6,780	1.3	U	INCO (3)
Copper, O free	102	S	403	6,780	1.1	U	CEL (4)
Copper, O free	102	S	403	6,780	<0.1	U	INCO (3)
Copper, O free	102	W	751	5,640	0.7	U	CEL (4)
Copper, O free	102	W	751	5,640	1.0	U	INCO (3)
Copper, O free	102	S	751	5,640	0.7	U	INCO (3)
Copper, O free	102	W	751	5,640	0.6	U	MEL (5)
Copper, O free	102	W	1,064	5,300	0.5	U	CEL (4)
Copper, O free	102	W	1,064	5,300	0.5	U	INCO (3)
Copper, O free	102	S	1,064	5,300	0.3	G	INCO (3)
Copper, O free	102	W	1,064	5,300	0.4	U	MEL (5)
Copper, O free	102	W	197	2,340	0.8	U	CEL (4)

Continued

Table 11. Continued

Alloy	CDA No.[a]	Environment[b]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Type of Corrosion[c]	Source[d]
Copper, O free	102	W	197	2,340	1.4	U	INCO (3)
Copper, O free	102	S	197	2,340	0.2	U	CEL (4)
Copper, O free	102	S	197	2,340	0.2	U	INCO (3)
Copper, O free	102	W	402	2,370	0.9	U	CEL (4)
Copper, O free	102	W	402	2,370	1.4	U	INCO (3)
Copper, O free	102	S	402	2,370	0.6	U	CEL (3)
Copper, O free	102	S	402	2,370	0.2	ET	INCO (3)
Copper, O free	102	W	181	5	1.4	P (22m)	CEL (4)
Copper, O free	102	W	181	5	1.8	G	INCO (3)
Copper, O free	102	W	366	5	1.2	G	INCO (3)
Copper, O free[e]	102	W	386	5	0.7	U	MEL (5)
Copper, O free	102	W	398	5	1.1	G, P (37m)	CEL (4)
Copper, O free	102	W	540	5	0.9	G, P (22m)	CEL (4)
Copper, O free	102	W	588	5	0.9	G, P (20m)	CEL (4)
Be-Cu[f]	170	W	123	5,640	0.5	U	NADC (7)
Be-Cu	170	W	751	5,640	0.5	U	NADC (7)
Be-Cu	170	W	197	2,340	0.0	NC	NADC (7)
Be-Cu	170	W	402	2,370	0.6	U	NADC (7)
Be-Cu	172[g]	W	123	5,640	0.5	U	NADC (7)
Be-Cu	172[h]	W	123	5,640	0.5	U	NADC (7)
Be-Cu	172[g]	W	751	5,640	0.5	U	NADC (7)
Be-Cu	172[h]	W	751	5,640	0.5	U	NADC (7)
Be-Cu	172[g]	W	197	2,340	0.2	U	NADC (7)
Be-Cu	172[h]	W	197	2,340	0.2	U	NADC (7)
Be-Cu	172[g]	W	402	2,370	0.5	U	NADC (7)
Be-Cu	172[h]	W	402	2,370	0.4	U	NADC (7)
Be-Cu	172	W	402	2,370	0.6	U	CEL (4)
Be-Cu	172	S	402	2,370	0.5	U	CEL (4)
Be-Cu	172	W	181	5	0.1	U	CEL (4)
Be-Cu	172	W	364	5	1.1	U	CEL (4)
Be-Cu	172	W	723	5	0.8	U	CEL (4)
Be-Cu	172	W	763	5	0.8	U	CEL (4)
Be-Cu[i]	172	W	402	2,370	0.5	U[j]	CEL (4)
Be-Cu[i]	172	S	402	2,370	0.5	U[j]	CEL (4)
Be-Cu[i]	172	W	181	5	0.1	U[j]	CEL (4)
Be-Cu[i]	172	W	364	5	1.0	U	CEL (4)
Be-Cu[i]	172	W	723	5	0.7	U	CEL (4)
Be-Cu[i]	172	W	763	5	0.8	U	CEL (4)
Be-Cu[k]	172	W	402	2,370	0.6	ET	CEL (4)
Be-Cu[k]	172	S	402	2,370	0.5	ET	CEL (4)

Continued

Table 11. Continued

Alloy	CDA No.[a]	Environment[b]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Type of Corrosion[c]	Source[d]
Be-Cu[k]	172	W	181	5	0.1	ET	CEL (4)
Be-Cu[k]	172	W	364	5	1.1	U	CEL (4)
Be-Cu[k]	172	W	723	5	0.7	U	CEL (4)
Be-Cu[k]	172	W	763	5	0.7	U	CEL (4)
Be-Cu chain[l]	825	W	402	2,370	0.5	U	CEL (4)
Be-Cu chain[l]	825	S	402	2,370	0.4	U	CEL (4)
Be-Cu chain[l]	825	W	181	5	0.1	U	CEL (4)
Be-Cu chain[l]	825	W	364	5	1.0	U	CEL (4)
Be-Cu chain[l]	825	W	723	5	0.8	U	CEL (4)
Be-Cu chain[l]	825	W	763	5	0.8	P (30.5m), C (7m)	CEL (4)

[a]Copper Development Association alloy numbers.

[b]W = totally exposed in seawater on sides of structure.
S = exposed in base of structure so that the lower portions of the specimens were embedded in the bottom sediments.

[c]Symbols for types of corrosion:

C = Crevice
ET = Etching
G = General
NC = No corrosion
P = Pitting
U = Uniform

Numbers indicate mils (i.e., 20 = 20 mils; 20m = 20 mils maximum)

[d]Numbers refer to references at end of report.

[e]Francis L. LaQue Corrosion Laboratory, INCO, Wrightsville Beach, N.C.

[f]Beryllium-copper

[g]Aged at 600°F

[h]Aged at 800°F

[i]MIG weld

[j]Uniform, weld bead etched

[k]TIG weld

[l]Cast

Table 12. Stress Corrosion of Coppers

Alloy	CDA No.[a]	Stress (ksi)	Yield Strength (%)	Exposure (day)	Depth (ft)	Specimens		Source[b]
						Exposed	Failed	
Copper, O free	102	11	75	197	2,340	3	0	CEL (4)
Copper, O free	102	11	75	402	2,370	3	0	CEL (4)
Be-Cu[c]	170	50	30	403	6,780	3	0	NADC (7)
Be-Cu	170	126	75	403	6,780	3	0	NADC (7)
Be-Cu	170	50	30	402	2,370	3	0	NADC (7)
Be-Cu	170	126	75	402	2,370	3	0	NADC (7)
Be-Cu	172[d]	53	30	403	6,780	3	0	NADC (7)
Be-Cu	172[d]	133	75	403	6,780	3	0	NADC (7)
Be-Cu	172[d]	53	30	402	2,370	3	0	NADC (7)
Be-Cu	172[d]	133	75	402	2,370	3	0	NADC (7)
Be-Cu	172[e]	37	30	403	6,780	3	0	NADC (7)
Be-Cu	172[e]	93	75	403	6,780	3	0	NADC (7)
Be-Cu	172[e]	37	30	402	2,370	3	0	NADC (7)
Be-Cu	172[e]	93	75	402	2,370	3	0	NADC (7)
Be-Cu	175	32	30	403	6,780	3	0	NADC (7)
Be-Cu	175	80	75	403	6,780	3	0	NADC (7)
Be-Cu	175	32	30	402	2,370	3	0	NADC (7)
Be-Cu	175	80	75	402	2,370	3	0	NADC (7)

[a] Copper Development Association alloy number.

[b] Numbers refer to references at end of report.

[c] Beryllium-copper

[d] Aged at 600°F

[e] Aged at 800°F

Table 13. Changes in Mechanical Properties of Coppers Due to Corrosion

Alloy	CDA No.[a]	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[b]
				Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
Copper, O free	102	123	5,640	33	+2	14	-6	52	-2	CEL (4)
Copper, O free	102	403	6,780	33	0	14	+9	52	-6	CEL (4)
Copper, O free	102	751	5,640	33	+4	14	+11	52	-6	CEL (4)
Copper, O free	102	197	2,340	33	-8	14	-18	52	-4	CEL (4)
Copper, O free	102	402	2,370	33	+2	14	+4	52	-7	CEL (4)
Copper, O free	102	181	5	33	+4	14	+20	52	-14	CEL (4)
Be-Cu[c]	170	123	5,640	188	0	167	0	5	0	NADC (7)
Be-Cu	170	751	5,640	188	-2	167	-2	5	-6	NADC (7)
Be-Cu	170	197	2,340	188	+11	167	+10	5	+4	NADC (7)
Be-Cu	170	402	2,370	188	-7	167	-6	5	0	NADC (7)
Be-Cu	172	402	2,370	176	-9	162	-8	4	-14	CEL (4)
Be-Cu[d]	172	402	2,370	161	-5	158	-2	3	+18	CEL (4)
Be-Cu[e]	172	402	2,370	166	-1	162	-6	3	-17	CEL (4)
Be-Cu	172	181	5	176	-7	162	-6	4	-29	CEL (4)
Be-Cu[d]	172	181	5	158	+3	157	-1	4	-29	CEL (4)
Be-Cu[e]	172	181	5	166	+3	162	-4	3	-17	CEL (4)
Be-Cu[f]	172	123	5,640	196	0	177	0	4	0	NADC (7)
Be-Cu[f]	172	751	5,640	196	-1	177	-2	4	-19	NADC (7)
Be-Cu[f]	172	197	2,340	196	0	177	0	4	0	NADC (7)
Be-Cu[f]	172	402	2,370	196	-8	177	-13	4	-26	NADC (7)
Be-Cu[g]	172	123	5,640	144	-2	124	-7	9	0	NADC (7)
Be-Cu[g]	172	751	5,640	144	-4	124	-10	9	+26	NADC (7)
Be-Cu[g]	172	197	2,340	144	+6	124	+10	9	+25	NADC (7)
Be-Cu[g]	172	402	2,370	144	-6	124	-12	9	+26	NADC (7)
Be-Cu	175	123	5,640	121	0	107	0	15	-20	NADC (7)
Be-Cu	175	751	5,640	121	-4	107	0	15	-13	NADC (7)
Be-Cu	175	197	2,340	121	0	107	0	15	0	NADC (7)
Be-Cu	175	402	2,370	121	-3	107	0	15	-23	NADC (7)

[a]Copper Development Association alloy number.

[b]Numbers refer to references at end of report.

[c]Beryllium-copper.

[d]MIG welded.

[e]TIG welded.

[f]Aged at 600°F.

[g]Aged at 800°F.

Table 14. Chemical Composition of Copper-Zinc Alloys (Brasses), Percent by Weight

Alloy	CDA No.[a]	Cu	Zn	Sn	Ni	Al	Mn	Fe	Other	Source[b]
Commercial bronze	220	90	10	–	–	–	–	–	–	INCO (3)
Red brass	230	85	15	–	–	–	–	–	–	INCO (3)
Red brass	230	85	15	–	–	–	–	–	–	MEL (5)
Commercial brass	268	66.47	33.51	<0.05	–	–	–	0.02	<0.01 Pb	CEL (4)
Yellow brass	270	68.48	31.50	<0.05	–	–	–	0.02	<0.01 Pb	CEL (4)
Yellow brass	270	65.0	35.0	–	–	–	–	–	–	INCO (3)
Muntz metal	280	60.69	39.29	–	–	–	–	<0.02	–	CEL (4)
Muntz metal	280	60.0	40.0	–	–	–	–	–	–	INCO (3)
Arsenical admiralty	443	71.19	27.77	1.00	–	–	–	0.01	0.027 As	CEL (4)
Arsenical admiralty	443	70.0	29.0	1.0	–	–	–	–	0.04 As	INCO (3)
Naval brass	464	60.46	38.74	0.69	–	–	–	0.03	0.08 Pb	CEL (4)
Naval brass	464	60.2	39.8	0.8	–	–	–	–	–	MEL (5)
Tobin bronze	–	58.94	39.07	0.89	nil	<0.10	–	1.10	<0.05 Pb	CEL (4)
Mn bronze A	675	56.0	42.0	–	–	1.0	0.1	1.0	–	INCO (3)
Mn bronze B	670	68.0	21.0	–	–	5.0	4.0	2.0	–	MEL (5)
Ni-Mn bronze[c]	868	54.58	34.48	0.70	3.77	1.73	3.06	1.66	0.02 Pb	CEL (4)
Al brass	–	78.0	20.0	–	–	2.0	–	–	–	INCO (3)
Ni brass	–	50.0	40.0	–	8.0	–	–	2.0	–	INCO (3)

[a]Copper Development Association alloy number.

[b]Numbers refer to references at end of report.

[c]Cast alloy.

Table 15. Corrosion Rates and Types of Corrosion of Copper-Zinc Alloys (Brasses)

Alloy	CDA No.[a]	Environment[b]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Type of Corrosion[c]	Source[d]
Commercial Bronze	220	W	123	5,640	0.6	U	INCO (3)
Commercial Bronze	220	S	123	5,640	0.3	U	INCO (3)
Commercial Bronze	220	W	403	6,780	0.6	U	INCO (3)
Commercial Bronze	220	S	403	6,780	<0.1	U	INCO (3)
Commercial Bronze	220	W	751	5,640	0.6	C (9)	INCO (3)
Commercial Bronze	220	S	751	5,640	0.4	C (20)	INCO (3)
Commercial Bronze	220	W	1,064	5,300	0.4	C (20)	INCO (3)
Commercial Bronze	220	S	1,064	5,300	0.6	U	INCO (3)
Commercial Bronze	220	W	197	2,340	0.3	U	INCO (3)
Commercial Bronze	220	S	197	2,340	0.1	NU-ET	INCO (3)
Commercial Bronze	220	W	402	2,370	0.2	SL-DZ	INCO (3)
Commercial Bronze	220	S	402	2,370	<0.1	SL-DZ	INCO (3)
Commercial Bronze	220	W	181	5	1.1	U	INCO (3)
Commercial Bronze	220	W	366	5	1.1	P (4)	INCO (3)
Red Brass	230	W	123	5,640	1.3	U	INCO (3)
Red Brass	230	S	123	5,640	1.7	SL-DZ	INCO (3)
Red Brass	230	W	123	5,640	1.9	U	MEL (5)
Red Brass	230	W	403	6,780	1.2	SL-DZ	INCO (3)
Red Brass	230	S	403	6,780	0.4	GBSL	INCO (3)
Red Brass	230	W	751	5,640	0.9	SL-DZ	INCO (3)
Red Brass	230	S	751	5,640	0.7	U	INCO (3)
Red Brass	230	W	751	5,640	0.7	U	MEL (5)
Red Brass	230	W	1,064	5,300	0.6	SL-DZ	INCO (3)
Red Brass	230	S	1,064	5,300	0.3	G	INCO (3)
Red Brass	230	W	1,064	5,300	0.6	U	MEL (5)
Red Brass	230	W	197	2,340	1.0	U	INCO (3)
Red Brass	230	S	197	2,340	0.1	U	INCO (3)
Red Brass	230	W	402	2,370	0.7	U	INCO (3)
Red Brass	230	S	402	2,370	<0.1	ET	INCO (3)
Red Brass	230	W	181	5	1.8	SL-DZ	INCO (3)
Red Brass	230	W	366	5	1.2	CR (6)	INCO (3)
Red Brass[e]	230	W	386	5	0.8	U	MEL (5)
Commercial Brass	268	W	1,064	5,300	0.8	S-DZ	CEL (4)
Yellow Brass	268	W	1,064	5,300	0.6	MO-DZ	CEL (4)
Yellow Brass	270	W	123	5,640	1.4	U	INCO (3)
Yellow Brass	270	S	123	5,640	1.3	U	INCO (3)
Yellow Brass	270	W	403	6,780	1.0	U	INCO (3)
Yellow Brass	270	S	403	6,780	0.2	GBSL	INCO (3)
Yellow Brass	270	W	751	5,640	2.5	SL-DZ	INCO (3)
Yellow Brass	270	S	751	5,640	0.6	SL-DZ	INCO (3)

Continued

Table 15. Continued.

Alloy	CDA No.[a]	Environment[b]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Type of Corrosion[c]	Source[d]
Yellow Brass	270	W	1,064	5,300	0.6	U	INCO (3)
Yellow Brass	270	S	1,064	5,300	0.5	U	INCO (3)
Yellow Brass	270	W	197	2,340	0.9	U	INCO (3)
Yellow Brass	270	S	197	2,340	0.2	NU-ET	INCO (3)
Yellow Brass	270	W	402	2,370	0.9	U	INCO (3)
Yellow Brass	270	S	402	2,370	0.1	ET	INCO (3)
Yellow Brass	270	W	181	5	2.1	U	INCO (3)
Yellow Brass	270	W	366	5	1.3	U	INCO (3)
Muntz Metal	280	W	123	5,640	1.6	SL-DZ	CEL (4)
Muntz Metal	280	W	123	5,640	2.1	U	INCO (3)
Muntz Metal	280	S	123	5,640	1.3	SL-DZ	CEL (4)
Muntz Metal	280	S	123	5,640	1.5	U	INCO (3)
Muntz Metal	280	W	403	6,780	2.6	SL-DZ	CEL (4)
Muntz Metal	280	W	403	6,780	3.3	S-DZ	INCO (3)
Muntz Metal	280	S	403	6,780	1.8	SL-DZ	CEL (4)
Muntz Metal	280	S	403	6,780	0.6	GBSL	INCO (3)
Muntz Metal	280	W	751	5,640	3.2	G-DZ	CEL (4)
Muntz Metal	280	W	751	5,640	4.0	S-DZ	INCO (3)
Muntz Metal	280	S	751	5,640	1.7	S-DZ	INCO (3)
Muntz Metal	280	W	1,064	5,300	2.3	S-DZ	INCO (3)
Muntz Metal	280	S	1,064	5,300	0.8	U	INCO (3)
Muntz Metal	280	W	197	2,340	0.7	SL-DZ; P (10)	CEL (4)
Muntz Metal	280	W	197	2,340	0.7	U	INCO (3)
Muntz Metal	280	S	197	2,340	0.5	SL-DZ; P (5)	CEL (4)
Muntz Metal	280	S	197	2,340	<0.1	SL-DZ[f]	INCO (3)
Muntz Metal	280	W	402	2,370	0.7	SL-DZ	CEL (4)
Muntz Metal	280	W	402	2,370	0.7	SL-DZ	INCO (3)
Muntz Metal	280	S	402	2,370	0.6	SL-DZ	CEL (4)
Muntz Metal	280	S	402	2,370	0.1	ET	INCO (3)
Muntz Metal	280	W	181	5	2.4	DZ	CEL (4)
Muntz Metal	280	W	181	5	3.4	SL-DZ	INCO (3)
Muntz Metal	280	W	366	5	3.7	S-DZ	INCO (3)
Muntz Metal	280	W	398	5	3.1	DZ, P (6)	CEL (4)
Muntz Metal	280	W	540	5	3.4	DZ, I-P	CEL (4)
Muntz Metal	280	W	588	5	3.3	DZ, I-P	CEL (4)
Arsenical Admiralty	443	W	123	5,640	1.0	U	CEL (4)
Arsenical Admiralty	443	W	123	5,640	1.1	U	INCO (3)
Arsenical Admiralty	443	S	123	5,640	1.0	U	CEL (4)
Arsenical Admiralty	443	S	123	5,640	1.0	U	INCO (3)
Arsenical Admiralty	443	W	403	6,780	0.7	U	CEL (4)
Arsenical Admiralty	443	W	403	6,780	0.8	U	INCO (3)

Continued

Table 15. Continued.

Alloy	CDA No.[a]	Environment[b]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Type of Corrosion[c]	Source[d]
Arsenical Admiralty	443	S	403	6,780	0.8	U	CEL (4)
Arsenical Admiralty	443	S	403	6,780	0.2	GBSL	INCO (3)
Arsenical Admiralty	443	W	751	5,640	0.6	U	CEL (4)
Arsenical Admiralty	443	W	751	5,640	0.7	U	INCO (3)
Arsenical Admiralty	443	S	751	5,640	0.4	U	CEL (4)
Arsenical Admiralty	443	S	751	5,640	0.5	U	INCO (3)
Arsenical Admiralty	443	W	1,064	5,300	0.5	U	INCO (3)
Arsenical Admiralty	443	S	1,064	5,300	0.5	U	INCO (3)
Arsenical Admiralty	443	W	197	2,340	0.6	U	CEL (4)
Arsenical Admiralty	443	W	197	2,340	1.0	U	INCO (3)
Arsenical Admiralty	443	S	197	2,340	0.2	U	CEL (4)
Arsenical Admiralty	443	S	197	2,340	<0.1	U	INCO (3)
Arsenical Admiralty	443	W	402	2,370	0.6	U	CEL (4)
Arsenical Admiralty	443	W	402	2,370	0.6	U	INCO (3)
Arsenical Admiralty	443	S	402	2,370	0.4	U	CEL (4)
Arsenical Admiralty	443	S	402	2,370	0.1	ET	INCO (3)
Arsenical Admiralty	443	W	181	5	1.3	U	CEL (4)
Arsenical Admiralty	443	W	181	5	1.8	G	INCO (3)
Arsenical Admiralty	443	W	366	5	1.3	U	INCO (3)
Arsenical Admiralty	443	W	608	5	1.1	U; I-P	CEL (4)
Naval Brass	464	W	123	5,640	1.2	U	MEL (5)
Naval Brass	464	W	751	5,640	0.6	U	MEL (5)
Naval Brass	464	W	1,064	5,300	0.7	U	MEL (5)
Naval Brass	464	W	1,064	5,300	1.0	S-DZ	CEL (4)
Naval Brass[e]	464	W	364	5	0.7	U	MEL (5)
Tobin Bronze	–	W	1,064	5,300	0.9	S-DZ	CEL (4)
Mn Bronze A	675	W	123	5,640	2.9	EX-DZ	INCO (3)
Mn Bronze A	675	S	123	5,640	2.0	EX-DZ	INCO (3)
Mn Bronze A	675	W	403	6,780	2.7	S-DZ	INCO (3)
Mn Bronze A	675	S	403	6,780	0.9	S-DZ	INCO (3)
Mn Bronze A	675	W	751	5,640	7.2	S-DZ	INCO (3)
Mn Bronze A	675	S	751	5,640	2.6	V-S-DZ	INCO (3)
Mn Bronze A	675	W	1,064	5,300	2.0	S-DZ	INCO (3)
Mn Bronze A	675	S	1,064	5,300	1.2	S-DZ	INCO (3)
Mn Bronze A	675	W	197	2,340	1.2	S-DZ	INCO (3)
Mn Bronze A	675	S	197	2,340	0.2	SL-DZ	INCO (3)
Mn Bronze A	675	W	402	2,370	0.8	S-DZ	INCO (3)
Mn Bronze A	675	S	402	2,370	<0.1	SL-DZ	INCO (3)
Mn Bronze A	675	W	181	5	4.8	S-DZ	INCO (3)
Mn Bronze A	675	W	366	5	1.9	S-DZ	INCO (3)

Continued

Table 15. Continued.

Alloy	CDA No.[a]	Environment[b]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Type of Corrosion[c]	Source[d]
Mn Bronze B	670	W	123	5,640	1.5	DZ	MEL (5)
Mn Bronze B	670	W	751	5,640	3.0	DZ	MEL (5)
Ni-Mn Bronze[g]	868	W	123	5,640	0.5	SL-DZ	CEL (4)
Ni-Mn Bronze	868	W	403	6,780	0.4	MD-DZ	CEL (4)
Ni-Mn Bronze	868	S	403	6,780	0.5	MD-DZ	CEL (4)
Ni-Mn Bronze	868	W	751	5,640	2.3	V-S-DZ	CEL (4)
Ni-Mn Bronze	868	W	197	2,340	0.4	SL-DZ	CEL (4)
Ni-Mn Bronze	868	S	197	2,340	0.4	SL-DZ	CEL (4)
Ni-Mn Bronze	868	W	402	2,340	1.6	SL-DZ	CEL (4)
Ni-Mn Bronze	868	S	402	2,340	2.9	SL-DZ	CEL (4)
Ni-Mn Bronze	868	W	181	5	<0.1	SL-DZ	CEL (4)
Ni-Mn Bronze	868	W	364	5	0.7	DZ	CEL (4)
Ni-Mn Bronze	868	W	723	5	2.9	DZ	CEL (4)
Ni-Mn Bronze	868	W	763	5	3.0	DZ	CEL (4)
Al Brass	–	W	123	5,640	0.7	U	INCO (3)
Al Brass	–	S	123	5,640	0.5	U	INCO (3)
Al Brass	–	W	403	6,780	0.4	U	INCO (3)
Al Brass	–	S	403	6,780	0.1	GBSL	INCO (3)
Al Brass	–	W	751	5,640	0.3	U	INCO (3)
Al Brass	–	S	751	5,640	0.1	U	INCO (3)
Al Brass	–	W	1,064	5,300	0.2	U	INCO (3)
Al Brass	–	S	1,064	5,300	0.8	G	INCO (3)
Al Brass	–	W	197	2,340	0.5	U	INCO (3)
Al Brass	–	S	197	2,340	<0.1	U	INCO (3)
Al Brass	–	W	402	2,370	0.3	U	INCO (3)
Al Brass	–	S	402	2,370	0.1	ET	INCO (3)
Al Brass	–	W	181	5	0.8	G	INCO (3)
Al Brass	–	W	366	5	0.4	P (4)	INCO (3)
Ni Brass	–	W	123	5,640	1.3	U	INCO (3)
Ni Brass	–	S	123	5,640	1.1	U	INCO (3)
Ni Brass	–	W	403	6,780	1.3	U	INCO (3)
Ni Brass	–	S	403	6,780	0.2	GBSL	INCO (3)
Ni Brass	–	W	751	5,640	1.0	U	INCO (3)
Ni Brass	–	S	751	5,640	0.7	U	INCO (3)
Ni Brass	–	W	1,064	5,300	0.8	U	INCO (3)
Ni Brass	–	S	1,064	5,300	0.5	U	INCO (3)
Ni Brass	–	W	197	2,340	0.8	U	INCO (3)
Ni Brass	–	S	197	2,340	<0.1	NU-ET	INCO (3)
Ni Brass	–	W	402	2,370	0.7	U	INCO (3)
Ni Brass	–	S	402	2,370	<0.1	ET	INCO (3)

Continued

Table 15. Continued.

Alloy	CDA No.[a]	Environment[b]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Type of Corrosion[c]	Source[d]
Ni Brass	—	W	181	5	1.1	U	INCO (3)
Ni Brass	—	W	366	5	0.9	U	INCO (3)

[a]Copper Development Association alloy number.

[b]W = Totally exposed in seawater on sides of structure; S = Exposed in base of structure so that the lower portions of the specimen were embedded in the bottom sediments.

[c]Symbols for types of corrosion:

C	= Crevice	MD	= Medium
CR	= Cratering	MO	= Moderate
DZ	= Dezincification	NU	= Nonuniform
ET	= Etching	P	= Pitting
EX	= Extensive	S	= Severe
G	= General	SL	= Slight
GBSL	= General below sediment line	U	= Uniform
I	= Incipient	V	= Very

Numbers indicate maximum depth in mils.

[d]Numbers refer to references at end of report.

[e]Francis L. LaQue Corrosion Laboratory, INCO, Wrightsville Beach, N.C.

[f]At spacer.

[g]Cast alloy.

Table 16. Stress Corrosion of Copper-Zinc Alloys (Brasses)

Alloy	CDA No.[a]	Stress (ksi)	Tensile Strength (%)	Exposure (day)	Depth (ft)	Specimens		Source[b]
						Exposed	Failed	
Arsenical admiralty	443	10.0	50	403	6,780	2	0	CEL (4)
Arsenical admiralty	443	14.0	75	403	6,780	2	0	CEL (4)
Arsenical admiralty	443	9.5	50	197	2,340	3	0	CEL (4)
Arsenical admiralty	443	14.3	75	197	2,340	3	0	CEL (4)
Arsenical admiralty	443	9.0	50	402	2,370	3	0	CEL (4)
Arsenical admiralty	443	13.4	75	402	2,370	3	0	CEL (4)
Muntz metal	280	12.0	50	403	6,780	2	0	CEL (4)
Muntz metal	280	18.0	75	403	6,780	2	0	CEL (4)
Muntz metal	280	12.2	50	197	2,340	3	0	CEL (4)
Muntz metal	280	18.3	75	197	2,340	3	0	CEL (4)
Muntz metal	280	17.7	50	402	2,370	3	0	CEL (4)
Muntz metal	280	26.5	75	402	2,370	3	0	CEL (4)

[a]Copper Development Association alloy number.

[b]Numbers refer to references at end of report.

Table 17. Changes in Mechanical Properties of Brasses Due to Corrosion

Alloy	CDA No.[a]	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[b]
				Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
Muntz metal	280	123	5,640	56	-4	24	-3	53	-6	CEL (4)
Muntz metal	280	403	6,780	56	-16	24	-12	53	-25	CEL (4)
Muntz metal	280	751	5,640	56	-32	24	-29	53	-31	CEL (4)
Muntz metal	280	197	2,340	56	-6	24	-17	53	-6	CEL (4)
Muntz metal	280	402	2,370	56	-8	24	-10	53	-15	CEL (4)
Muntz metal	280	181	5	56	-7	24	-16	53	-13	CEL (4)
Arsenical admiralty	443	123	5,640	51	0	19	+3	66	-2	CEL (4)
Arsenical admiralty	443	403	6,780	51	-2	19	-5	66	+1	CEL (4)
Arsenical admiralty	443	751	5,680	51	-2	19	-1	66	+1	CEL (4)
Arsenical admiralty	443	197	2,340	51	-6	19	-21	66	-3	CEL (4)
Arsenical admiralty	443	402	2,370	51	-2	19	-3	66	-1	CEL (4)
Arsenical admiralty	443	181	5	51	-2	19	-10	66	-12	CEL (4)
Ni-Mn bronze	868	123	5,640	71	-2	31	-10	20	+25	CEL (4)
Ni-Mn bronze	868	403	6,780	71	-33	31	-8	20	-60	CEL (4)
Ni-Mn bronze	868	751	5,640	71	-40	31	-21	20	-58	CEL (4)
Ni-Mn bronze	868	197	2,340	71	-3	31	-17	20	+16	CEL (4)
Ni-Mn bronze	868	402	2,370	71	-6	31	+53	20	-61	CEL (4)
Ni-Mn bronze	868	181	5	71	-10	31	+14	20	-35	CEL (4)

[a]Copper Development Association alloy number.

[b]Numbers refer to references at end of report.

Table 18. Chemical Composition of Copper Alloys (Bronzes), Percent by Weight

Alloy	CDA No.[a]	Cu	Sn	Zn	Ni	Al	Fe	Si	Pb	P	Mn	Source[b]
G bronze[c]	–	88.0	2.0	10.0	–	–	–	–	–	–	–	INCO (3)
Modified G bronze[c]	–	88.0	8.0	4.0	–	–	–	–	–	–	–	INCO (3)
M bronze[c]	–	88.2	6.0	4.0	–	–	–	–	2.0	–	–	INCO (3)
Leaded Sn bronze[c]	–	85.0	5.0	5.0	–	–	–	–	5.0	–	–	INCO (3)
Phosphor bronze A	510	94.64	4.94	<0.10	–	–	<0.05	–	–	0.26	–	CEL (4)
Phosphor bronze A	510	96.0	4.0	–	–	–	–	–	–	0.25	–	INCO (3)
Phosphor bronze A	510	95.62	4.44	<0.10	–	–	<0.05	–	–	0.06	–	CEL (4)
Phosphor bronze D	524	90.00	9.23	<0.10	–	–	<0.05	–	–	0.17	–	CEL (4)
Al bronze, 5%	606	95.0	–	–	–	5.0	–	–	–	–	–	INCO (3)
Al bronze, 5%	606	95.11	–	–	–	4.76	<0.05	–	–	–	–	CEL (4)
Al bronze, 5%	606	–	–	–	–	–	–	–	–	–	–	Boeing (6)
Al bronze, 7%	614	90.11	–	0.15	–	6.59	3.15	–	<0.02	–	–	CEL (4)
Al bronze, 7%	614	90.0	–	–	–	7.0	3.0	–	–	–	–	INCO (3)
Al bronze, 7%	614	88.0	–	–	–	9.0	3.0	–	–	–	–	NADC (7)
Al bronze, 10%[c]	953	89.0	–	–	–	10.0	1.0	–	–	–	–	INCO (3)
Al bronze, 11%[c]	954	86.0	–	–	–	10.0	4.0	–	–	–	–	INCO (3)
Al bronze, 11%[c]	954	86.5	–	–	–	10.0	3.5	–	–	–	–	MEL (5)
Al bronze, 13%[c]	–	83.0	–	–	–	13.0	4.0	–	–	–	–	INCO (3)
Ni-Al bronze	–	83.5	–	–	2.5	10.0	4.0	–	–	–	–	MEL (5)
Ni-Al bronze No. 1	–	80.0	–	–	4.0	11.0	4.0	–	–	–	1.0	INCO (3)
Ni-Al bronze No. 1	–	80.0	–	–	4.0	10.0	4.0	–	–	–	–	MEL (5)
Ni-Al bronze No. 2	–	80.0	–	–	5.0	10.0	4.0	–	–	–	0.5	INCO (3)
Ni-Al bronze No. 3	–	80.0	–	–	5.0	9.0	3.5	–	–	–	3.0	INCO (3)
Si bronze, 3%	653	97.0	–	–	–	–	–	3.0	–	–	–	INCO (3)
Si bronze A	655	95.49	–	–	–	–	<0.02	3.28	–	–	1.18	CEL (4)
Si bronze A	655	95.0	–	–	–	–	–	3.0	–	–	1.0	INCO (3)
Si bronze A	655	96.0	–	–	–	–	–	3.0	–	–	1.0	Boeing (6)
Ni-Vee bronze A[c]	–	88.0	5.0	2.0	5.0	–	–	–	–	–	–	INCO (3)
Ni-Vee bronze B[c]	–	87.0	5.0	2.0	5.0	–	–	1.0	–	–	–	INCO (3)
Ni-Vee bronze C[c]	–	80.0	5.0	5.0	5.0	–	–	5.0	–	–	–	INCO (3)

[a]Copper Development Association alloy number.

[b]Numbers refer to references at end of report.

[c]Cast alloy.

Table 19. Corrosion Rates and Types of Corrosion of Copper Alloys (Bronzes)

Alloy	CDA No.[a]	Environment[b]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Type of Corrosion[c]	Source[d]
G Bronze[e]	–	W	123	5,640	0.5	U	INCO (3)
G Bronze	–	S	123	5,640	0.3	U	INCO (3)
G Bronze	–	W	403	6,780	0.7	U	INCO (3)
G Bronze	–	S	403	6,780	0.1	GBSL	INCO (3)
G Bronze	–	W	751	5,640	0.7	U	INCO (3)
G Bronze	–	S	751	5,640	0.3	U	INCO (3)
G Bronze	–	W	1,064	5,300	0.3	U	INCO (3)
G Bronze	–	S	1,064	5,300	0.4	U	INCO (3)
G Bronze	–	W	197	2,340	0.2	U	INCO (3)
G Bronze	–	S	197	2,340	<0.1	I-C	INCO (3)
G Bronze	–	W	402	2,370	0.3	U	INCO (3)
G Bronze	–	S	402	2,370	<0.1	ET	INCO (3)
G Bronze	–	W	181	5	1.3	G	INCO (3)
G Bronze	–	W	366	5	1.2	CR (9)	INCO (3)
Modified G Bronze[e]	–	W	123	5,640	0.5	U	INCO (3)
Modified G Bronze	–	S	123	5,640	0.3	U	INCO (3)
Modified G Bronze	–	W	403	6,780	0.4	U	INCO (3)
Modified G Bronze	–	S	403	6,780	<0.1	U	INCO (3)
Modified G Bronze	–	W	751	5,640	0.7	U	INCO (3)
Modified G Bronze	–	S	751	5,640	0.4	C (19)	INCO (3)
Modified G Bronze	–	W	1,064	5,300	0.4	C (18); P	INCO (3)
Modified G Bronze	–	S	1,064	5,300	0.5	U	INCO (3)
Modified G Bronze	–	W	197	2,340	0.3	U	INCO (3)
Modified G Bronze	–	S	197	2,340	0.2	NU-ET	INCO (3)
Modified G Bronze	–	W	402	2,370	0.3	U	INCO (3)
Modified G Bronze	–	S	402	2,370	<0.1	ET	INCO (3)
Modified G Bronze	–	W	181	5	1.3	G	INCO (3)
Modified G Bronze	–	W	366	5	1.0	CR (7)	INCO (3)
M Bronze[e]	–	W	123	5,640	0.5	U	INCO (3)
M Bronze	–	S	123	5,640	0.4	U	INCO (3)
M Bronze	–	W	403	6,780	0.4	U	INCO (3)
M Bronze	–	S	403	6,780	<0.1	U	INCO (3)
M Bronze	–	W	751	5,640	0.7	U	INCO (3)
M Bronze	–	S	751	5,640	0.3	U	INCO (3)
M Bronze	–	W	1,064	5,300	0.4	U	INCO (3)
M Bronze	–	S	1,064	5,300	0.4	U	INCO (3)
M Bronze	–	W	197	2,340	0.4	U	INCO (3)
M Bronze	–	S	197	2,340	0.1	ET	INCO (3)
M Bronze	–	W	402	2,370	0.3	U	INCO (3)
M Bronze	–	S	402	2,370	<0.1	ET	INCO (3)
M Bronze	–	W	181	5	1.6	G	INCO (3)
M Bronze	–	W	366	5	1.1	CR (2)	INCO (3)
Leaded Sn Bronze[e]	–	W	123	5,640	0.4	U	INCO (3)
Leaded Sn Bronze	–	S	123	5,640	0.2	U	INCO (3)
Leaded Sn Bronze	–	W	403	6,780	0.5	U	INCO (3)
Leaded Sn Bronze	–	S	403	6,780	0.1	U	INCO (3)
Leaded Sn Bronze	–	W	751	5,640	0.6	U	INCO (3)
Leaded Sn Bronze	–	S	751	5,640	3.2	S-G	INCO (3)
Leaded Sn Bronze	–	W	1,064	5,300	0.4	U	INCO (3)

Continued

Table 19. Continued.

Alloy	CDA No.[a]	Environment[b]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Type of Corrosion[c]	Source[d]
Leaded Sn Bronze	–	S	1,064	5,300	0.3	U	INCO (3)
Leaded Sn Bronze	–	W	197	2,340	0.5	U	INCO (3)
Leaded Sn Bronze	–	S	197	2,340	<0.1	NU-ET	INCO (3)
Leaded Sn Bronze	–	W	402	2,370	0.5	U	INCO (3)
Leaded Sn Bronze	–	S	402	2,370	<0.1	ET	INCO (3)
Leaded Sn Bronze	–	W	181	5	1.4	G	INCO (3)
Leaded Sn Bronze	–	W	366	5	1.3	CR (5)	INCO (3)
P Bronze A	510	W	123	5,640	0.6	U	CEL (4)
P Bronze A	510	W	123	5,640	0.5	U	INCO (3)
P Bronze A	510	S	123	5,640	0.4	U	CEL (4)
P Bronze A	510	S	123	5,640	0.4	U	INCO (3)
P Bronze A	510	W	403	6,780	0.2	ET	CEL (4)
P Bronze A	510	W	403	6,780	0.3	U	INCO (3)
P Bronze A	510	S	403	6,780	0.3	ET	CEL (4)
P Bronze A	510	S	403	6,780	0.1	GBSL	INCO (3)
P Bronze A	510	W	751	5,640	0.2	ET	CEL (4)
P Bronze A	510	W	751	5,640	0.3	U	INCO (3)
P Bronze A	510	S	751	5,640	0.1	U	INCO (3)
P Bronze A	510	W	1,064	5,300	0.4	U	CEL (4)
P Bronze A	510	W	1,064	5,300	0.2	U	INCO (3)
P Bronze A	510	S	1,064	5,300	0.4	G	INCO (3)
P Bronze A	510	W	197	2,340	0.3	U	CEL (4)
P Bronze A	510	W	197	2,340	0.4	U	INCO (3)
P Bronze A	510	S	197	2,340	0.3	*f*	CEL (4)
P Bronze A	510	S	197	2,340	<0.1	I-C	INCO (3)
P Bronze A	510	W	402	2,370	0.1	ET	CEL (4)
P Bronze A	510	W	402	2,370	0.2	U	INCO (3)
P Bronze A	510	S	402	2,370	0.2	EWO	CEL (4)
P Bronze A	510	S	402	2,370	0.2	ET	INCO (3)
P Bronze A	510	W	181	5	1.1	U	CEL (4)
P Bronze A	510	W	181	5	1.6	P (4)	INCO (3)
P Bronze A	510	W	366	5	1.3	CR (5)	INCO (3)
P Bronze A	510	W	588	5	1.3	CR (15); C (3)	CEL (4)
P Bronze A	510	W	608	5	1.1	CR (15)	CEL (4)
P Bronze D	524	W	123	5,640	0.5	U	CEL (4)
P Bronze D	524	S	123	5,640	0.4	U	CEL (4)
P Bronze D	524	W	403	6,780	0.2	ET	CEL (4)
P Bronze D	524	S	403	6,780	0.3	ET	CEL (4)
P Bronze D	524	W	751	5,640	0.3	U	CEL (4)
P Bronze D	524	S	751	5,640	0.4	NU	CEL (4)
P Bronze D	524	W	197	2,340	0.4	U	CEL (4)
P Bronze D	524	S	197	2,340	0.2	U	CEL (4)
P Bronze D	524	W	402	2,370	<0.1	U	CEL (4)
P Bronze D	524	S	402	2,370	<0.1	U	CEL (4)
P Bronze D	524	W	181	5	1.1	NU	CEL (4)
P Bronze D	524	W	398	5	0.9	CR (4)	CEL (4)
P Bronze D	524	W	540	5	0.7	CR (2)	CEL (4)
P Bronze D	524	W	608	5	0.7	CR (7); C (5)	CEL (4)
Al Bronze, 5%	606	W	123	5,640	0.6	U	INCO (3)
Al Bronze, 5%	606	S	123	5,640	0.4	U	INCO (3)

Continued

Table 19. Continued.

Alloy	CDA No.[a]	Environment[b]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Type of Corrosion[c]	Source[d]
Al Bronze, 5%	606	W	403	6,780	0.2	SL-DA	INCO (3)
Al Bronze, 5%	606	S	403	6,780	<0.1	U	INCO (3)
Al Bronze, 5%	606	W	751	5,640	0.3	SL-DA	INCO (3)
Al Bronze, 5%	606	S	751	5,640	0.2	V-SL-DA	INCO (3)
Al Bronze, 5%	606	W	1,064	5,300	0.2	NU	CEL (4)
Al Bronze, 5%	606	W	1,064	5,300	0.2	CR (5)	INCO (3)
Al Bronze, 5%	606	S	1,064	5,300	0.5	G	INCO (3)
Al Bronze, 5%	606	W	197	2,340	0.4	U	INCO (3)
Al Bronze, 5%	606	S	197	2,340	0.2	NU-ET	INCO (3)
Al Bronze, 5%	606	W	197	2,340	0.2	U	Boeing (6)
Al Bronze, 5%	606	W	402	2,370	0.2	U	INCO (3)
Al Bronze, 5%	606	S	402	2,370	0.1	ET	INCO (3)
Al Bronze, 5%	606	W	181	5	1.1	G	INCO (3)
Al Bronze, 5%	606	W	366	5	0.7	G	INCO (3)
Al Bronze, 7%	614	·	123	5,640	0.5	SL-DA	CEL (4)
Al Bronze, 7%	614	W	123	5,640	0.6	U	INCO (3)
Al Bronze, 7%	614	S	123	5,640	0.3	U	CEL (4)
Al Bronze, 7%	614	S	123	5,640	0.4	U	INCO (3)
Al Bronze, 7%	614	W	403	6,780	0.7	SL-DA; C (12); P (12)	CEL (4)
Al Bronze, 7%	614	W	403	6,780	0.2	U	INCO (3)
Al Bronze, 7%	614	S	403	6,780	0.7	SL-DA; C (13); P (16)	CEL (4)
Al Bronze, 7%	614	S	403	6,780	<0.1	SL-DA	INCO (3)
Al Bronze, 7%	614	W	403	6,780	NC	NC	NADC (7)
Al Bronze, 7%	614	W	751	5,640	0.5	MD-DA; C (7); P (12)	CEL (4)
Al Bronze, 7%	614	W	751	5,640	1.5	G	INCO (3)
Al Bronze, 7%	614	S	751	5,640	0.2	V-SL-DA	INCO (3)
Al Bronze, 7%	614	W	1,064	5,300	0.2	CR (7)	INCO (3)
Al Bronze, 7%	614	S	1,064	5,300	0.2	MO-DA	INCO (3)
Al Bronze, 7%	614	W	197	2,340	0.3	U	CEL (4)
Al Bronze, 7%	614	W	197	2,340	0.3	U	INCO (3)
Al Bronze, 7%	614	S	197	2,340	0.1	U	CEL (4)
Al Bronze, 7%	614	S	197	2,340	0.2	ET	INCO (3)
Al Bronze, 7%	614	W	402	2,370	0.2	U	CEL (4)
Al Bronze, 7%	614	W	402	2,370	0.2	ET	INCO (3)
Al Bronze, 7%	614	S	402	2,370	0.2	U	INCO (3)
Al Bronze, 7%	614	S	402	2,370	0.1	SL-DA	INCO (3)
Al Bronze, 7%	614	W	181	5	2.9	NU-DA	CEL (4)
Al Bronze, 7%	614	W	181	5	0.8	G	INCO (3)
Al Bronze, 7%	614	W	366	5	0.6	G	INCO (3)
Al Bronze, 7%	614	W	588	5	0.9	SL-DA; CR (44); C (20)	CEL (4)
Al Bronze, 10%[e]	–	W	123	5,640	0.7	SL-DA	INCO (3)
Al Bronze, 10%	–	S	123	5,640	0.6	SL-DA	INCO (3)
Al Bronze, 10%	–	W	403	6,780	0.7	MO-DA	INCO (3)
Al Bronze, 10%	–	S	403	6,780	<0.1	SL-DA	INCO (3)
Al Bronze, 10%	–	W	751	5,640	2.3	G	INCO (3)
Al Bronze, 10%	–	S	751	5,640	0.9	U; SL-DA	INCO (3)
Al Bronze, 10%	–	W	1,064	5,300	0.2	U	INCO (3)
Al Bronze, 10%	–	S	1,064	5,300	0.4	SL-DA	INCO (3)
Al Bronze, 10%	–	W	197	2,340	0.3	MO-DA	INCO (3)
Al Bronze, 10%	–	S	197	2,340	0.2	MO-DA	INCO (3)

Continued

Table 19. Continued.

Alloy	CDA No.[a]	Environment[b]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Type of Corrosion[c]	Source[d]
Al Bronze, 10%	–	W	402	2,370	0.3	S-DA	INCO (3)
Al Bronze, 10%	–	S	402	2,370	<0.1	MO-DA	INCO (3)
Al Bronze, 10%	–	W	181	5	2.1	MO-DA	INCO (3)
Al Bronze, 10%	–	W	366	5	1.3	MO-DA	INCO (3)
Al Bronze, 11%[e]	–	W	123	5,640	0.4	U	MEL (5)
Al Bronze, 11%	–	W	123	5,640	0.5	V-SL-DA	INCO (3)
Al Bronze, 11%	–	S	123	5,640	0.4	V-SL-DA	INCO (3)
Al Bronze, 11%	–	W	403	6,780	0.1	SL-DA	INCO (3)
Al Bronze, 11%	–	S	403	6,780	<0.1	SL-DA	INCO (3)
Al Bronze, 11%	–	W	751	5,640	0.8	SL-DA	INCO (3)
Al Bronze, 11%	–	W	751	5,640	0.3	U-P	MEL (5)
Al Bronze, 11%	–	S	751	5,640	0.1	V-SL-DA	INCO (3)
Al Bronze, 11%	–	W	1,064	5,300	0.1	SL-DA	INCO (3)
Al Bronze, 11%	–	S	1,064	5,300	0.2	MO-DA	INCO (3)
Al Bronze, 11%	–	W	197	2,340	0.2	SL-DA[g]	INCO (3)
Al Bronze, 11%	–	S	197	2,340	<0.1	SL-DA[h]	INCO (3)
Al Bronze, 11%	–	W	402	2,370	0.2	MO-DA	INCO (3)
Al Bronze, 11%	–	S	402	2,370	<0.1	SL-DA	INCO (3)
Al Bronze, 11%	–	W	366	5	1.1	U	INCO (3)
Al Bronze, 13%[e]	–	W	123	5,640	0.5	V-SL-DA	INCO (3)
Al Bronze, 13%	–	S	123	5,640	0.5	V-SL-DA	INCO (3)
Al Bronze, 13%	–	W	403	6,780	0.6	S-DA	INCO (3)
Al Bronze, 13%	–	S	403	6,780	<0.1	SL-DA	INCO (3)
Al Bronze, 13%	–	W	751	5,640	1.9	S-DA	INCO (3)
Al Bronze, 13%	–	S	751	5,640	0.5	MO-DA	INCO (3)
Al Bronze, 13%	–	W	1,064	5,300	0.6	S-DA	INCO (3)
Al Bronze, 13%	–	S	1,064	5,300	0.3	SL-DA	INCO (3)
Al Bronze, 13%	–	W	197	2,340	0.4	MO-DA	INCO (3)
Al Bronze, 13%	–	S	197	2,340	<0.1	SL-DA	INCO (3)
Al Bronze, 13%	–	W	402	2,370	0.3	MO-DA	INCO (3)
Al Bronze, 13%	–	S	402	2,370	<0.1	SL-DA	INCO (3)
Al Bronze, 13%	–	W	181	5	2.1	S-DA	INCO (3)
Al Bronze, 13%	–	W	366	5	1.9	S-DA	INCO (3)
Ni-Al Bronze	–	W	123	5,640	0.6	P	MEL (5)
Ni-Al Bronze	–	W	751	5,640	0.4	P (21)	MEL (5)
Ni-Al Bronze No. 1	–	W	123	5,640	0.5	U	MEL (5)
Ni-Al Bronze No. 1	–	W	123	5,640	0.4	I-P	INCO (3)
Ni-Al Bronze No. 1	–	S	123	5,640	0.2	I-P	INCO (3)
Ni-Al Bronze No. 1	–	W	403	6,780	0.3	I-P	INCO (3)
Ni-Al Bronze No. 1	–	S	403	6,780	0.1	U	INCO (3)
Ni-Al Bronze No. 1	–	W	751	5,640	1.1	C (16); P	INCO (3)
Ni-Al Bronze No. 1	–	W	751	5,640	0.2	P	MEL (5)
Ni-Al Bronze No. 1	–	S	751	5,640	0.3	P (17)	INCO (3)
Ni-Al Bronze No. 1	–	W	1,064	5,300	0.1	P (8)	INCO (3)
Ni-Al Bronze No. 1	–	S	1,064	5,300	1.2	CR (30)	INCO (3)
Ni-Al Bronze No. 1	–	W	197	2,340	0.3	U	INCO (3)
Ni-Al Bronze No. 1	–	S	197	2,340	<0.1	U-ET	INCO (3)

Continued

Table 19. Continued.

Alloy	CDA No.[a]	Environment[b]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Type of Corrosion[c]	Source[d]
Ni-Al Bronze No. 2	–	W	123	5,640	0.5	U	INCO (3)
Ni-Al Bronze No. 2	–	S	123	5,640	0.3	U	INCO (3)
Ni-Al Bronze No. 2	–	W	403	6,780	0.2	I-P	INCO (3)
Ni-Al Bronze No. 2	–	S	403	6,780	0.1	U	INCO (3)
Ni-Al Bronze No. 2	–	W	751	5,640	0.5	SL-DA	INCO (3)
Ni-Al Bronze No. 2	–	S	751	5,640	0.2	C (13)	INCO (3)
Ni-Al Bronze No. 2	–	W	1,064	5,300	0.2	C (5)	INCO (3)
Ni-Al Bronze No. 2	–	S	1,064	5,300	0.5	CR (21)	INCO (3)
Ni-Al Bronze No. 2	–	W	197	2,340	0.3	U	INCO (3)
Ni-Al Bronze No. 2	–	S	197	2,340	0.1	U	INCO (3)
Ni-Al Bronze No. 2	–	W	402	2,370	0.2	U	INCO (3)
Ni-Al Bronze No. 2	–	S	402	2,370	<0.1	ET	INCO (3)
Ni-Al Bronze No. 2	–	W	181	5	1.0	C (8)	INCO (3)
Ni-Al Bronze No. 2	–	W	366	5	0.4	U	INCO (3)
Ni-Al Bronze No. 3	–	W	123	5,640	0.4	U	INCO (3)
Ni-Al Bronze No. 3	–	S	123	5,640	0.3	U	INCO (3)
Ni-Al Bronze No. 3	–	W	403	6,780	0.2	U	INCO (3)
Ni-Al Bronze No. 3	–	S	403	6,780	<0.1	NU-ET	INCO (3)
Ni-Al Bronze No. 3	–	W	751	5,640	0.2	I-P	INCO (3)
Ni-Al Bronze No. 3	–	S	751	5,640	0.1	U	INCO (3)
Ni-Al Bronze No. 3	–	W	1,064	5,300	<0.1	P (4)	INCO (3)
Ni-Al Bronze No. 3	–	S	1,064	5,300	0.2	CR (10)	INCO (3)
Ni-Al Bronze No. 3	–	W	197	2,340	0.3	U	INCO (3)
Ni-Al Bronze No. 3	–	S	197	2,340	0.2	U	INCO (3)
Si Bronze, 3%	653	W	123	5,640	1.3	U	INCO (3)
Si Bronze, 3%	653	S	123	5,640	1.5	U	INCO (3)
Si Bronze, 3%	653	W	403	6,780	1.2	MO-CO	INCO (3)
Si Bronze, 3%	653	S	403	6,780	0.4	GBSL	INCO (3)
Si Bronze, 3%	653	W	751	5,640	1.0	U	INCO (3)
Si Bronze, 3%	653	S	751	5,640	0.7	U	INCO (3)
Si Bronze, 3%	653	W	1,064	5,300	0.6	MO-CO	INCO (3)
Si Bronze, 3%	653	S	1,064	5,300	0.4	SL-CO	INCO (3)
Si Bronze, 3%	653	W	197	2,340	1.1	U	INCO (3)
Si Bronze, 3%	653	S	197	2,340	0.1	NU-ET	INCO (3)
Si Bronze, 3%	653	W	402	2,370	1.2	U	INCO (3)
Si Bronze, 3%	653	S	402	2,370	0.2	ET	INCO (3)
Si Bronze, 3%	653	W	181	5	1.7	U	INCO (3)
Si Bronze, 3%	653	W	366	5	1.1	G	INCO (3)
Si Bronze A	655	W	123	5,640	1.6	U	CEL (4)
Si Bronze A	655	W	123	5,640	1.4	U	INCO (3)
Si Bronze A	655	S	123	5,640	1.8	U	CEL (4)
Si Bronze A	655	S	123	5,640	1.5	U	INCO (3)
Si Bronze A	655	W	403	6,780	1.2	CO	CEL (4)
Si Bronze A	655	W	403	6,780	1.2	U	INCO (3)
Si Bronze A	655	S	403	6,780	1.8	ET	CEL (4)
Si Bronze A	655	S	403	6,780	0.2	GBSL	INCO (3)
Si Bronze A	655	W	751	5,640	0.8	S-CO	CEL (4)
Si Bronze A	655	W	751	5,640	1.4	U	INCO (3)
Si Bronze A	655	S	751	5,640	0.9	G	INCO (3)

Continued

Table 19. Continued.

Alloy	CDA No.[a]	Environment[b]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Type of Corrosion[c]	Source[d]
Si Bronze A	655	W	1,064	5,300	0.6	SL-CO	INCO (3)
Si Bronze A	655	S	1,064	5,300	0.4	U	INCO (3)
Si Bronze A	655	W	197	2,340	0.8	U	Boeing (6)
Si Bronze A	655	W	197	2,340	0.9	U	CEL (4)
Si Bronze A	655	W	197	2,340	1.1	U	INCO (3)
Si Bronze A	655	S	197	2,340	0.6	U	CEL (4)
Si Bronze A	655	S	197	2,340	0.2	U	INCO (3)
Si Bronze A	655	W	402	2,370	1.0	ET	CEL (4)
Si Bronze A	655	W	402	2,370	0.8	U	INCO (3)
Si Bronze A	655	S	402	2,370	0.8	ET	CEL (4)
Si Bronze A	655	S	402	2,370	0.1	ET	INCO (3)
Si Bronze A	655	W	181	5	1.8	U	CEL (4)
Si Bronze A	655	W	181	5	1.6	G	INCO (3)
Si Bronze A	655	W	366	5	1.2	G	INCO (3)
Si Bronze A	655	W	398	5	1.1	G	CEL (4)
Si Bronze A	655	W	540	5	2.5	CR (30); C (15)	CEL (4)
Si Bronze A	655	W	588	5	0.9	CR (9)	CEL (4)
Ni-Vee Bronze A[e]	–	W	123	5,640	0.7	U	INCO (3)
Ni-Vee Bronze A	–	S	123	5,640	0.5	U	INCO (3)
Ni-Vee Bronze A	–	W	403	6,780	0.6	U	INCO (3)
Ni-Vee Bronze A	–	S	403	6,780	0.3	U	INCO (3)
Ni-Vee Bronze A	–	W	751	5,640	2.6	S[i]	INCO (3)
Ni-Vee Bronze A	–	S	751	5,640	0.4	U	INCO (3)
Ni-Vee Bronze A	–	W	1,064	5,300	2.2	CR (20)	INCO (3)
Ni-Vee Bronze A	–	S	1,064	5,300	0.3	U	INCO (3)
Ni-Vee Bronze A	–	W	197	2,340	0.6	U	INCO (3)
Ni-Vee Bronze A	–	S	197	2,340	<0.1	NU-ET	INCO (3)
Ni-Vee Bronze A	–	W	402	2,370	0.4	U	INCO (3)
Ni-Vee Bronze A	–	S	402	2,370	<0.1	ET	INCO (3)
Ni-Vee Bronze A	–	W	181	5	2.0	P (7)	INCO (3)
Ni-Vee Bronze A	–	W	366	5	1.5	CR (10)	INCO (3)
Ni-Vee Bronze B[e]	–	W	123	5,640	0.6	U	INCO (3)
Ni-Vee Bronze B	–	S	123	5,640	0.4	U	INCO (3)
Ni-Vee Bronze B	–	W	403	6,780	0.5	U	INCO (3)
Ni-Vee Bronze B	–	S	403	6,780	0.1	U	INCO (3)
Ni-Vee Bronze B	–	W	751	5,640	0.5	U	INCO (3)
Ni-Vee Bronze B	–	S	751	5,640	0.3	U	INCO (3)
Ni-Vee Bronze B	–	W	1,064	5,300	0.3	U	INCO (3)
Ni-Vee Bronze B	–	S	1,064	5,300	0.4	U	INCO (3)
Ni-Vee Bronze B	–	W	197	2,340	0.6	U	INCO (3)
Ni-Vee Bronze B	–	S	197	2,340	<0.1	NU-ET	INCO (3)
Ni-Vee Bronze B	–	W	402	2,370	1.2	U	INCO (3)
Ni-Vee Bronze B	–	S	402	2,370	<0.1	ET	INCO (3)
Ni-Vee Bronze B	–	W	181	5	1.8	P (4)	INCO (3)
Ni-Vee Bronze B	–	W	366	5	1.3	CR (6)	INCO (3)
Ni-Vee Bronze C[e]	–	W	123	5,640	0.8	U	INCO (3)
Ni-Vee Bronze C	–	S	123	5,640	0.5	U	INCO (3)
Ni-Vee Bronze C	–	W	403	6,780	0.8	U	INCO (3)
Ni-Vee Bronze C	–	S	403	6,780	0.2	U	INCO (3)
Ni-Vee Bronze C	–	W	751	5,640	2.0	G	INCO (3)

Continued

Table 19. Continued.

Alloy	CDA No.[a]	Environment[b]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Type of Corrosion[c]	Source[d]
Ni-Vee Bronze C	–	S	751	5,640	0.4	U	INCO (3)
Ni-Vee Bronze C	–	W	1,064	5,300	0.5	U	INCO (3)
Ni-Vee Bronze C	–	S	1,064	5,300	0.3	U	INCO (3)
Ni-Vee Bronze C	–	W	197	2,340	0.8	U	INCO (3)
Ni-Vee Bronze C	–	S	197	2,340	<0.1	ET	INCO (3)
Ni-Vee Bronze C	–	W	402	2,370	0.6	U	INCO (3)
Ni-Vee Bronze C	–	S	402	2,370	0.1	ET	INCO (3)
Ni-Vee Bronze C	–	W	181	5	1.8	U	INCO (3)
Ni-Vee Bronze C	–	W	366	5	1.5	CR (5)	INCO (3)

[a]Copper Development Association alloy number.

[b]W = Totally exposed in seawater on sides of structure; S = Exposed in base of structure so that a portion of each specimen was exposed in the bottom sediments.

[c]Symbols for types of corrosion:

C	= Crevice	I	= Incipient
CO	= Coppering, a selective attack where copper appears on surface similar to dezincification	MD	= Medium
		MO	= Moderate
CR	= Cratering	NU	= Nonuniform
DA	= Dealuminification	P	= Pitting
ET	= Etching	S	= Severe
EWO	= Etched only in the water	SL	= Slight
G	= General	U	= Uniform
GBSL	= General below sediment line	V	= Very

Numbers indicate maximum depth in mils.

[d]Numbers refer to references at end of report.

[e]Cast alloy.

[f]Pitting in bottom sediment, 12 mils maximum.

[g]At spacer.

[h]At crevice.

[i]Severe corrosion in small area.

Table 20. Stress Corrosion of Copper Alloys (Bronzes)

Alloy	CDA No.[a]	Stress (ksi)	Tensile Strength (%)	Exposure (day)	Depth (ft)	Specimens		Source[b]
						Exposed	Failed	
Phosphor bronze A	510	12.0	50	403	6,780	2	0	CEL (4)
Phosphor bronze A	510	19.0	75	403	6,780	2	0	CEL (4)
Phosphor bronze A	510	12.5	50	197	2,340	3	0	CEL (4)
Phosphor bronze A	510	18.7	75	197	2,340	3	0	CEL (4)
Phosphor bronze A	510	12.6	50	402	2,370	3	0	CEL (4)
Phosphor bronze A	510	19.0	75	402	2,370	3	0	CEL (4)
Phosphor bronze D	524	10.0	35	403	6,780	2	0	CEL (4)
Phosphor bronze D	524	14.0	50	403	6,780	2	0	CEL (4)
Phosphor bronze D	524	21.0	75	403	6,780	2	0	CEL (4)
Phosphor bronze D	524	9.8	35	197	2,340	3	0	CEL (4)
Phosphor bronze D	524	13.9	50	197	2,340	3	0	CEL (4)
Phosphor bronze D	524	20.9	75	197	2,340	3	0	CEL (4)
Phosphor bronze D	524	16.4	50	402	2,370	3	0	CEL (4)
Phosphor bronze D	524	24.5	75	402	2,370	3	0	CEL (4)
Al bronze, 5%	606	18.0	35	403	6,780	2	0	CEL (4)
Al bronze, 5%	606	26.0	50	403	6,780	2	0	CEL (4)
Al bronze, 5%	606	38.0	75	403	6,780	2	0	CEL (4)
Al bronze, 5%	606	17.9	35	197	2,340	3	0	CEL (4)
Al bronze, 5%	606	25.6	50	197	2,340	3	0	CEL (4)
Al bronze, 5%	606	38.4	75	197	2,340	3	0	CEL (4)
Al bronze, 5%	606	28.3	50	402	2,370	3	0	CEL (4)
Al bronze, 5%	606	42.5	75	402	2,370	3	0	CEL (4)
Si bronze A	655	10.0	35	403	6,780	2	0	CEL (4)
Si bronze A	655	14.0	50	403	6,780	2	0	CEL (4)
Si bronze A	655	21.0	75	403	6,780	2	0	CEL (4)
Si bronze A	655	9.6	35	197	2,340	3	0	CEL (4)
Si bronze A	655	13.8	50	197	2,340	3	0	CEL (4)
Si bronze A	655	20.6	75	197	2,340	3	0	CEL (4)
Si bronze A	655	10.8	50	402	2,370	3	0	CEL (4)
Si bronze A	655	16.2	75	402	2,370	3	0	CEL (4)

[a]Copper Development Association alloy number.

[b]Numbers refer to references at end of report.

Table 21. Changes in Mechanical Properties of Copper Alloys (Bronzes) Due to Corrosion

Alloy	CDA No.[a]	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[b]
				Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
Phosphor bronze A	510	123	5,640	51	0	25	-3	64	+3	CEL (4)
Phosphor bronze A	510	403	6,780	51	+1	25	-1	64	+2	CEL (4)
Phosphor bronze A	510	751	5,640	51	+1	25	-1	64	-1	CEL (4)
Phosphor bronze A	510	197	2,340	51	-3	25	-13	64	-1	CEL (4)
Phosphor bronze A	510	402	2,370	51	-1	25	-3	64	-3	CEL (4)
Phosphor bronze A	510	181	5	51	0	25	-7	64	-2	CEL (4)
Phosphor bronze D	524	123	5,640	64	+1	28	0	70	0	CEL (4)
Phosphor bronze D	524	403	6,780	64	+2	28	+1	70	+3	CEL (4)
Phosphor bronze D	524	751	5,640	64	+2	28	+3	70	-1	CEL (4)
Phosphor bronze D	524	197	2,340	64	0	28	-3	70	+3	CEL (4)
Phosphor bronze D	524	402	2,370	64	+1	28	+1	70	-1	CEL (4)
Phosphor bronze D	524	181	5	64	-1	28	+1	70	+4	CEL (4)
Al bronze, 5%	606	123	5,640	85	0	51	+2	45	-9	CEL (4)
Al bronze, 5%	606	403	6,780	85	-1	51	0	45	-29	CEL (4)
Al bronze, 5%	606	751	5,640	85	0	51	+1	45	-27	CEL (4)
Al bronze, 5%	606	197	2,340	85	0	51	-2	45	-7	CEL (4)
Al bronze, 5%	606	402	2,370	85	0	51	0	45	-12	CEL (4)
Al bronze, 5%	606	181	5	85	-3	51	-3	45	-20	CEL (4)
Si bronze A	655	123	5,640	64	+2	28	+4	61	-2	CEL (4)
Si bronze A	655	403	6,780[c]	64	-1	28	-4	61	-1	CEL (4)
Si bronze A	655	403	6,780[d]	64	-25	28	-18	61	-40	CEL (4)
Si bronze A	655	751	5,640	64	-1	28	-5	61	-1	CEL (4)
Si bronze A	655	197	2,340	64	-2	28	-14	61	-3	CEL (4)
Si bronze A	655	402	2,370	64	-1	28	-3	61	-2	CEL (4)
Si bronze A	655	181	5	64	-1	28	-7	61	+3	CEL (4)

[a]Copper Development Association alloy number.

[b]Numbers refer to references at end of report.

[c]Totally exposed in water.

[d]Partially embedded in the bottom sediments.

Table 22. Chemical Composition of Copper-Nickel Alloys, Percent by Weight

Alloy	CDA No.[a]	Cu	Ni	Fe	Mn	Zn	Pb	Source[b]
Cu-Ni, 95-5	704	91.98	6.25	1.24	0.53	–	–	CEL (4)
Cu-Ni, 90-10	706	89.04	9.42	1.16	0.38	–	–	CEL (4)
Cu-Ni, 90-10	706	89.0	10.0	1.4	0.5	–	–	INCO (3)
Cu-Ni, 90-10	706	88.7	10.0	1.3	–	–	–	MEL (5)
Cu-Ni, 90-10[c]	962	86.0	11.0	1.4	1.3	–	–	INCO (3)
Cu-Ni, 80-20	710	78.62	20.41	0.62	0.35	–	–	CEL (4)
Cu-Ni, 80-20	711	80.0	20.0	0.03	0.2	–	–	INCO (3)
Cu-Ni, 70-30	715	68.61	30.53	0.53	0.33	–	–	CEL (4)
Cu-Ni, 70-30	715	69.0	30.0	0.6	0.4	–	–	INCO (3)
Cu-Ni, 70-30	715	69.4	30.0	0.6	–	–	–	MEL (5)
Cu-Ni, 70-30	716	64.02	29.95	5.27	0.75	–	–	CEL (4)
Cu-Ni, 55-45	–	54.0	45.0	0.1	1.0	–	–	INCO (3)
Cu-Ni-Zn-Pb	–	62.0	25.0	–	–	8.0	5.0	INCO (3)
Nickel-silver	752	65.0	18.0	–	–	17.0	–	INCO (3)

[a]Copper Development Association alloy number.

[b]Numbers refer to references at end of report.

[c]Cast alloy.

Table 23. Corrosion Rates and Types of Corrosion of Copper-Nickel Alloys

Alloy	CDA No.[a]	Environment[b]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Type of Corrosion[c]	Source[d]
Cu-Ni, 95-5	704	W	123	5,640	1.5	U	CEL (4)
Cu-Ni, 95-5	704	S	123	5,640	1.5	U	CEL (4)
Cu-Ni, 95-5	704	W	403	6,780	0.8	U	CEL (4)
Cu-Ni, 95-5	704	S	403	6,780	0.8	U	CEL (4)
Cu-Ni, 95-5	704	W	751	5,640	0.7	U	CEL (4)
Cu-Ni, 95-5	704	S	751	5,640	0.6	U	CEL (4)
Cu-Ni, 95-5	704	W	197	2,340	0.9	U	CEL (4)
Cu-Ni, 95-5	704	S	197	2,340	0.6	U	CEL (4)
Cu-Ni, 95-5	704	W	402	2,370	0.9	U	CEL (4)
Cu-Ni, 95-5	704	S	402	2,370	0.8	U	CEL (4)
Cu-Ni, 90-10	706	W	123	5,640	0.9	U	MEL (5)
Cu-Ni, 90-10	706	W	123	5,640	1.6	U	CEL (4)
Cu-Ni, 90-10	706	W	123	5,640	0.8	U	INCO (3)
Cu-Ni, 90-10	706	S	123	5,640	1.2	U	CEL (4)
Cu-Ni, 90-10	706	S	123	5,640	0.8	U	INCO (3)
Cu-Ni, 90-10	706	W	403	6,780	0.8	U	CEL (4)
Cu-Ni, 90-10	706	W	403	6,780	0.6	U	INCO (3)
Cu-Ni, 90-10	706	S	403	6,780	0.7	U	CEL (4)
Cu-Ni, 90-10	706	S	403	6,780	<0.1	U	INCO (3)
Cu-Ni, 90-10	706	W	751	5,640	0.5	U	MEL (5)
Cu-Ni, 90-10	706	W	751	5,640	0.7	U	CEL (4)
Cu-Ni, 90-10	706	W	751	5,640	0.6	U	INCO (3)
Cu-Ni, 90-10	706	S	751	5,640	0.5	U	INCO (3)
Cu-Ni, 90-10	706	W	1,064	5,300	0.6	U	MEL (5)
Cu-Ni, 90-10	706	W	1,064	5,300	0.7	U	INCO (3)
Cu-Ni, 90-10	706	S	1,064	5,300	0.2	G	INCO (3)
Cu-Ni, 90-10	706	W	197	2,340	0.8	U	CEL (4)
Cu-Ni, 90-10	706	W	197	2,340	0.8	U	INCO (3)
Cu-Ni, 90-10	706	S	197	2,340	0.5	U	CEL (4)
Cu-Ni, 90-10	706	S	197	2,340	<0.1	U	INCO (3)

Continued

Table 23. Continued.

Alloy	CDA No.[a]	Environment[b]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Type of Corrosion[c]	Source[d]
Cu-Ni, 90-10	706	W	402	2,370	0.6	U[e]	CEL (4)
Cu-Ni, 90-10	706	W	402	2,370	0.8	U	INCO (3)
Cu-Ni, 90-10	706	S	402	2,370	0.5	U[e]	CEL (4)
Cu-Ni, 90-10	706	S	402	2,370	0.1	ET	INCO (3)
Cu-Ni, 90-10	706	W	181	5	1.1	NU	CEL (4)
Cu-Ni, 90-10	706	W	181	5	0.9	U	INCO (3)
Cu-Ni, 90-10	706	W	366	5	0.6	U	INCO (3)
Cu-Ni, 90-10[f]	706	W	386	5	0.3	U	MEL (5)
Cu-Ni, 90-10	706	W	608	5	0.5	U	CEL (4)
Cu-Ni, 90-10[g]	962	W	402	2,370	0.7	U	INCO (3)
Cu-Ni, 90-10[g]	962	S	402	2,370	0.1	ET	INCO (3)
Cu-Ni, 90-10[g]	962	W	181	5	1.1	U	INCO (3)
Cu-Ni, 90-10[g]	962	W	366	5	0.9	U	INCO (3)
Cu-Ni, 80-20	710	W	123	5,640	1.2	U	CEL (4)
Cu-Ni, 80-20	711	W	123	5,640	1.9	U	INCO (3)
Cu-Ni, 80-20	710	S	123	5,640	1.3	U	CEL (4)
Cu-Ni, 80-20	711	S	123	5,640	1.1	U	INCO (3)
Cu-Ni, 80-20	710	W	403	6,780	1.2	ET	CEL (4)
Cu-Ni, 80-20	711	W	403	6,780	1.5	U	INCO (3)
Cu-Ni, 80-20	710	S	403	6,780	1.0	ET	CEL (4)
Cu-Ni, 80-20	711	S	403	6,780	0.1	EBSL	INCO (3)
Cu-Ni, 80-20	710	W	751	5,640	0.8	U	CEL (4)
Cu-Ni, 80-20	711	W	751	5,640	1.3	U	INCO (3)
Cu-Ni, 80-20	711	S	751	5,640	1.0	U	INCO (3)
Cu-Ni, 80-20	711	W	1,064	5,300	1.0	U	INCO (3)
Cu-Ni, 80-20	711	S	1,064	5,300	0.5	U	INCO (3)
Cu-Ni, 80-20	710	W	197	2,340	0.7	U	CEL (4)
Cu-Ni, 80-20	711	W	197	2,340	1.1	U	INCO (3)
Cu-Ni, 80-20	710	S	197	2,340	0.5	U	CEL (4)

Continued

Table 23. Continued.

Alloy	CDA No.[a]	Environment[b]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Type of Corrosion[c]	Source[d]
Cu-Ni, 80-20	711	S	197	2,340	<0.1	SL-ET	INCO (3)
Cu-Ni, 80-20	710	W	402	2,370	0.6	U	CEL (4)
Cu-Ni, 80-20	711	W	402	2,370	1.1	U	INCO (3)
Cu-Ni, 80-20	710	S	402	2,370	0.5	U[b]	CEL (4)
Cu-Ni, 80-20	711	S	402	2,370	0.2	ET	INCO (3)
Cu-Ni, 80-20	711	W	181	5	2.8	G	INCO (3)
Cu-Ni, 80-20	711	W	366	5	1.9	G	INCO (3)
Cu-Ni, 70-30, 0.5 Fe	715	W	123	5,640	1.0	U	MEL (5)
Cu-Ni, 70-30, 0.5 Fe	715	W	123	5,640	1.2	U	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	W	123	5,640	1.3	U	INCO (3)
Cu-Ni, 70-30, 0.5 Fe	715	S	123	5,640	0.8	U	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	S	123	5,640	0.9	U	INCO (3)
Cu-Ni, 70-30, 0.5 Fe	715	W	403	6,780	1.2	U	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	W	403	6,780	1.2	U	INCO (3)
Cu-Ni, 70-30, 0.5 Fe	715	S	403	6,780	1.1	U	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	S	403	6,780	0.2	G	INCO (3)
Cu-Ni, 70-30, 0.5 Fe	715	W	751	5,640	0.4	U	MEL (5)
Cu-Ni, 70-30, 0.5 Fe	715	W	751	5,640	0.7	U	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	W	751	5,640	0.9	G	INCO (3)
Cu-Ni, 70-30, 0.5 Fe	715	S	751	5,640	0.7	U	INCO (3)
Cu-Ni, 70-30, 0.5 Fe	715	W	1,064	5,300	0.5	U	MEL (5)
Cu-Ni, 70-30, 0.5 Fe	715	W	1,064	5,300	0.6	U	INCO (3)
Cu-Ni, 70-30, 0.5 Fe	715	S	1,064	5,300	0.5	G	INCO (3)
Cu-Ni, 70-30, 0.5 Fe	715	W	123	2,500	0.6	U	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	W	197	2,340	0.7	U	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	W	197	2,340	0.9	U	INCO (3)
Cu-Ni, 70-30, 0.5 Fe	715	S	197	2,340	0.2	U	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	S	197	2,340	<0.1	SL-ET	INCO (3)
Cu-Ni, 70-30, 0.5 Fe	715	W	402	2,370	0.5	U	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	W	402	2,370	0.6	U	INCO (3)

Continued

Table 23. Continued.

Alloy	CDA No.[a]	Environment[b]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Type of Corrosion[c]	Source[d]
Cu-Ni, 70-30, 0.5 Fe	715	S	402	2,370	0.4	U	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	S	402	2,370	0.1	ET	INCO (3)
Cu-Ni, 70-30, 0.5 Fe	715	W	181	5	0.5	U	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	W	181	5	0.5	G	INCO (3)
Cu-Ni, 70-30, 0.5 Fe	715	W	366	5	0.4	G	INCO (3)
Cu-Ni, 70-30, 0.5 Fe[f]	715	W	386	5	0.2	U	MEL (5)
Cu-Ni, 70-30, 0.5 Fe	715	W	398	5	0.4	P (7)	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	W	608	5	0.3	I-P	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	W	123	5,640	0.2	U	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	S	123	5,640	0.2	U	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	W	403	6,780	0.1	ET	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	S	403	6,780	0.1	ET	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	W	751	5,640	0.5	C (16); NU-P (16); CO	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	S	751	5,640	0.2	C (14); NU-P (24); CO	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	W	197	2,340	0.1	U	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	S	197	2,340	0.1	U	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	W	402	2,370	0.1	U	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	S	402	2,370	0.1	U	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	W	181	5	0.8	I-P; C (5)	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	W	398	5	0.7	CR (17); U	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	W	608	5	0.6	C (13); CR (18)	CEL (4)
Cu-Ni, 55-45	—	W	123	5,640	0.7	U	INCO (3)
Cu-Ni, 55-45	—	S	123	5,640	0.7	U	INCO (3)
Cu-Ni, 55-45	—	W	403	6,780	1.2	U	INCO (3)
Cu-Ni, 55-45	—	S	403	6,780	<0.1	SL-ET	INCO (3)
Cu-Ni, 55-45	—	W	751	5,640	1.0	U	INCO (3)
Cu-Ni, 55-45	—	S	751	5,640	0.5	U	INCO (3)
Cu-Ni, 55-45	—	W	1,064	5,300	1.0	G	INCO (3)
Cu-Ni, 55-45	—	S	1,064	5,300	0.5	C to PR (50); S-E	INCO (3)

Continued

Table 23. Continued.

Alloy	CDA No.[a]	Environment[b]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Type of Corrosion[c]	Source[d]
Cu-Ni, 55-45	–	W	197	2,340	0.8	U	INCO (3)
Cu-Ni, 55-45	–	S	197	2,340	0.2	I-C; I-P	INCO (3)
Cu-Ni, 55-45	–	W	402	2,370	0.7	U	INCO (3)
Cu-Ni, 55-45	–	S	402	2,370	0.1	ET	INCO (3)
Cu-Ni, 55-45	–	W	181	5	1.8	U	INCO (3)
Cu-Ni, 55-45	–	W	366	5	1.2	U	INCO (3)
Cu-Ni-Zn-Pb	–	W	123	5,640	0.9	U	INCO (3)
Cu-Ni-Zn-Pb	–	S	123	5,640	0.6	U	INCO (3)
Cu-Ni-Zn-Pb	–	W	403	6,780	0.8	U	INCO (3)
Cu-Ni-Zn-Pb	–	S	403	6,780	0.1	GBSL	INCO (3)
Cu-Ni-Zn-Pb	–	W	751	5,640	0.6	U	INCO (3)
Cu-Ni-Zn-Pb	–	S	751	5,640	0.5	U	INCO (3)
Cu-Ni-Zn-Pb	–	W	1,064	5,300	0.5	U	INCO (3)
Cu-Ni-Zn-Pb	–	S	1,064	5,300	0.3	U	INCO (3)
Cu-Ni-Zn-Pb	–	W	197	2,340	0.5	U	INCO (3)
Cu-Ni-Zn-Pb	–	S	197	2,340	<0.1	SL-ET	INCO (3)
Cu-Ni-Zn-Pb	–	W	402	2,370	0.4	U	INCO (3)
Cu-Ni-Zn-Pb	–	S	402	2,370	<0.1	ET	INCO (3)
Cu-Ni-Zn-Pb	–	W	181	5	1.0	U	INCO (3)
Cu-Ni-Zn-Pb	–	W	366	5	0.7	U	INCO (3)
Nickel-Silver	752	W	123	5,640	2.0	U	INCO (3)
Nickel-Silver	752	S	123	5,640	2.6	U	INCO (3)
Nickel-Silver	752	W	403	6,780	1.4	U	INCO (3)
Nickel-Silver	752	S	403	6,780	0.5	GBSL	INCO (3)
Nickel-Silver	752	W	751	5,640	1.5	U	INCO (3)
Nickel-Silver	752	S	751	5,640	0.8	U	INCO (3)
Nickel-Silver	752	W	1,064	5,300	0.6	U	INCO (3)
Nickel-Silver	752	S	1,064	5,300	0.4	G	INCO (3)
Nickel-Silver	752	W	197	2,340	1.0	U	INCO (3)

Continued

Table 23. Continued.

Alloy	CDA No.[a]	Environment[b]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Type of Corrosion[c]	Source[d]
Nickel-Silver	752	S	197	2,340	<0.1	SL-ET	INCO (3)
Nickel-Silver	752	W	402	2,370	1.0	U	INCO (3)
Nickel-Silver	752	S	402	2,370	0.1	ET	INCO (3)
Nickel-Silver	752	W	181	5	1.1	U	INCO (3)
Nickel-Silver	752	W	366	5	0.7	U	INCO (3)

[a]Copper Development Association alloy number.

[b]W = Totally exposed in seawater on sides of structure; S = Exposed in base of structure so that a portion of each specimen was embedded in the bottom sediments.

[c]Symbols for types of corrosion:

C	= Crevice	GBSL	= General below sediment line
CO	= Coppering, a selective attack where copper appears on surface	I	= Incipient
		NU	= Nonuniform
CR	= Cratering	P	= Pitting
E	= Edge	PR	= Perforation
ET	= Etching	S	= Severe
EBSL	= Etched below sediment line	SL	= Slight
G	= General	U	= Uniform

Numbers indicate maximum depth in mils.

[d]Numbers refer to references at end of report.

[e]Much less below sediment line.

[f]Exposed at Francis L. LaQue Corrosion Laboratory, INCO, Wrightsville Beach, N.C.

[g]Cast alloy.

[h]No visible corrosion below sediment line.

Table 24. Stress Corrosion of Copper-Nickel Alloys

Alloy	CDA No.[a]	Stress (ksi)	Tensile Strength (%)	Exposure (day)	Depth (ft)	Specimens		Source[b]
						Exposed	Failed	
Cu-Ni, 95-5	704	16.0	50	403	6,780	2	0	CEL (4)
Cu-Ni, 95-5	704	24.0	75	403	6,780	2	0	CEL (4)
Cu-Ni, 95-5	704	16.0	50	197	2,340	3	0	CEL (4)
Cu-Ni, 95-5	704	24.0	75	197	2,340	3	0	CEL (4)
Cu-Ni, 95-5	704	12.9	50	402	2,370	3	0	CEL (4)
Cu-Ni, 95-5	704	19.3	75	402	2,370	3	0	CEL (4)
Cu-Ni, 90-10	706	34.4	50	402	2,370	3	0	CEL (4)
Cu-Ni, 90-10	706	52.0	75	402	2,370	3	0	CEL (4)
Cu-Ni, 80-20	710	15.0	75	403	6,780	2	0	CEL (4)
Cu-Ni, 80-20	710	15.0	75	197	2,340	3	0	CEL (4)
Cu-Ni, 80-20	710	8.9	50	402	2,370	3	0	CEL (4)
Cu-Ni, 80-20	710	13.3	75	402	2,370	3	0	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	13.0	50	403	6,780	2	0	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	20.0	75	403	6,780	2	0	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	13.2	50	197	2,340	3	0	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	19.8	75	197	2,340	3	0	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	14.0	50	402	2,370	3	0	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	21.0	75	402	2,370	3	0	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	14.0	35	403	6,780	2	0	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	21.0	50	403	6,780	2	0	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	31.0	75	403	6,780	2	0	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	14.4	35	197	2,340	3	0	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	20.6	50	197	2,340	3	0	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	30.9	75	197	2,340	3	0	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	26.6	50	402	2,370	3	0	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	39.9	75	402	2,370	3	0	CEL (4)

[a]Copper Development Association alloy number.

[b]Numbers refer to references at end of report.

Table 25. ·Changes in Mechanical Properties of Copper-Nickel Alloys Due to Corrosion

Alloy	CDA No.[a]	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[b]
				Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
Cu-Ni, 95-5	704	123	5,640	48	+1	32	+16	33	+2	CEL (4)
Cu-Ni, 95-5	704	403	6,780	48	+2	32	+3	33	-5	CEL (4)
Cu-Ni, 95-5	704	751	5,640	48	-1	32	-3	33	+2	CEL (4)
Cu-Ni, 95-5	704	197	2,340	48	-4	32	-9	33	+7	CEL (4)
Cu-Ni, 95-5	704	402	2,370	48	-1	32	-6	33	+4	CEL (4)
Cu-Ni, 90-10	706	123	5,640	43	+3	16	+11	42	0	CEL (4)
Cu-Ni, 90-10	706	403	6,780	43	+3	16	+6	42	-5	CEL (4)
Cu-Ni, 90-10	706	751	5,640	43	+3	16	+9	42	-2	CEL (4)
Cu-Ni, 90-10	706	197	2,340	43	-1	16	0	42	-2	CEL (4)
Cu-Ni, 90-10	706	402	2,370	43	+4	16	+13	42	-6	CEL (4)
Cu-Ni, 90-10	706	181	5	43	+4	16	+9	42	-18	CEL (4)
Cu-Ni, 80-20	710	123	5,640	49	0	21	-3	44	+2	CEL (4)
Cu-Ni, 80-20	710	403	6,780	49	+2	21	-2	44	-3	CEL (4)
Cu-Ni, 80-20	710	751	5,640	49	+1	21	-2	44	-3	CEL (4)
Cu-Ni, 80-20	710	197	2,340	49	+1	21	-6	44	+1	CEL (4)
Cu-Ni, 80-20	710	402	2,370	49	+1	21	-2	44	-2	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	123	5,640	58	+1	26	-2	41	+3	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	403	6,780	58	-25	26	-1	41	-3	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	751	5,640	58	-25	26	-4	41	-4	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	197	2,340	58	-3	26	-14	41	+1	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	402	2,370	58	+2	26	-3	41	-3	CEL (4)
Cu-Ni, 70-30, 0.5 Fe	715	181	5	58	+3	26	-9	41	-13	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	123	5,640	78	+2	41	+5	35	+1	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	403	6,780	78	-1	41	-3	35	-1	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	751	5,640	78	+3	41	+5	35	-9	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	197	2,340	78	+1	41	-4	35	0	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	402	2,370	78	+7	41	+10	35	-8	CEL (4)
Cu-Ni, 70-30, 5.0 Fe	716	181	5	78	+3	41	+6	35	-18	CEL (4)

[a]Copper Development Association alloy number.

[b]Numbers refer to references at end of report.

SECTION 4

NICKEL ALLOYS

Nickel and its alloys are passive in moving seawater, but are subject to pitting and concentration cell (crevice) corrosion in stagnant seawater. Their passivity is due to the presence of an impervious oxide layer on their surfaces which breaks down under certain conditions. Fouling organisms, deposits, and crevices which restrict the availability of oxygen to localized areas cause such breakdowns. Where sufficient oxygen is not available to repair the breaks in the protective film, pitting and crevice (concentration cell) corrosion occur. Thus, in seawater, pitting and crevice corrosion are the most prevalent modes of attack.

Corrosion rates calculated from weight losses due to localized corrosion are meaningless because they present an untrue picture of the corrosion behavior of the alloy. Corrosion rates such as mils-per-year connote a uniform thickness of metal lost over a period of time, assuming uniform corrosion. Hence, a very low corrosion rate resulting from a few deep pits or crevice corrosion in one area will present a very misleading picture of the corrosion behavior of an alloy in that particular environment.

The data on the nickel alloys were obtained from the reports given in References 3 through 19 and 23. They are separated into different groups (nickels, nickel-copper-alloys, and nickel alloys) for comparison and discussion purposes.

The chemical compositions, corrosion rates and types of corrosion, and changes in mechanical properties due to corrosion of the nickels are given in Tables 26 to 28; those of the nickel-copper alloys in Tables 29 to 31; those of the nickel alloys in Tables 32 to 34; and the resistance to stress corrosion in Table 35.

The effects of depth and the effect of the concentration of oxygen in seawater on the corrosion of the nickels, the nickel-copper alloys, and the nickel alloys are shown in Figures 15 and 16.

4.1. NICKELS

The chemical compositions of the nickels are given in Table 26, their corrosion rates and types of corrosion in Table 27, and the changes in their mechanical properties due to corrosion in Table 28.

4.1.1. Duration of Exposure

The corrosion rates and types of corrosion of the seven nickels (94% minimum nickel) are given in Table 27. Pitting, crevice, and edge (on the sheared ends) localized types of corrosion were responsible for practically all the corrosion. The edge corrosion was caused by microcracks and microcrevices that formed during the shearing operation; this illustrates dramatically the corrosion damage that can be caused by this fabricating procedure. Lateral penetration, initiated at a sheared edge, of as much as an inch during 6 months of exposure was found. To prevent this type of corrosion, all deformed metal created during shearing or punching operations must be removed by machining, grinding, or reaming.

Because the corrosion of the nickels was localized, no definite correlation with duration of exposure was possible. However, the severity of pitting and crevice corrosion increased with increasing time of exposure at depth as well as at the surface. Corrosion rates increased with duration of exposure at the 6,000-foot depth, although they were neither progressive nor constant. In some cases corrosion rates were considerably higher during shorter times of exposure than after longer times of exposure. Corrosion rates at the 2,500-foot depth were constant with increasing time of exposure.

4.1.2. Effect of Depth

The severity and frequency of pitting and crevice corrosion were much greater at the surface than at depth. Also, the average corrosion rates were greater at the surface than at depth, although they did not decrease progressively with increasing depth as shown in Figure 16. The curves in Figure 16 are based on average values for each group of alloys.

4.1.3. Effect of Concentration of Oxygen

The severity and frequency of pitting and crevice corrosion, in general, increased with increasing concentration of oxygen in seawater. The average corrosion rates increased progressively, but not constantly, with increasing concentration of oxygen in seawater as shown in Figure 17.

4.1.4. Effect of Welding

The weld beads were preferentially corroded when nickel Ni-200 was welded by manual shielded metal-arc welding using welding electrode 141, and by TIG welding using filler metal 61. The weld beads were severely pitted when welded with electrode 141. The weld beads and heat-affected zones were perforated when welded with filler metal 61. This preferential attack of the weld bead materials indicates that they were anodic to the parent sheet metal.

4.1.5. Mechanical Properties

The effect of exposure on the mechanical properties of nickel Ni-200 is shown in Table 28. The mechanical properties were not affected by exposure at depth for 1,064 days or for 181 days at the surface.

4.2. NICKEL-COPPER ALLOYS

The chemical compositions of the nickel-copper alloys are given in Table 29, their corrosion rates and types of corrosion in Table 30, and the changes in their mechanical properties due to corrosion in Table 31.

4.2.1. Duration of Exposure

The corrosion rates and types of corrosion of seven nickel-copper alloys are given in Table 30. Except for the cast alloys 410 and 505, the predominant types of corrosion were pitting and crevice. At the 6,000-foot depth there was an overall tendency for the corrosion rates of the cast alloys to decrease with increasing duration of exposure, but this tendency was neither progressive nor constant. Because the corrosion of the other nickel-copper alloys was localized (pitting and crevice corrosion), no definite correlation with duration of exposure was possible either at depth or at the surface. However, the intensity of pitting and crevice corrosion, in general, increased with increasing duration of exposure both at depth and at the surface.

4.2.2. Effect of Depth

The severity and frequency of pitting and crevice corrosion were much greater at the surface than at depth. Also, the average corrosion rates were greater at the surface than at depth, although they did not decrease progressively or constantly with increasing depth, as shown in Figure 16. Although these corrosion rates are unreliable because they are based upon localized corrosion weight losses, they do substantiate the conclusion based upon the frequency and severity of pitting and crevice corrosion.

4.2.3. Effect of Concentration of Oxygen

The severity and frequency of pitting and crevice corrosion, in general, increased with increasing concentration of oxygen in seawater. Even though pitting and crevice corrosion were the predominant types for these alloys in seawater, their average corrosion rates calculated from weight losses increased linearly with increasing concentration of oxygen, as shown in Figure 17.

4.2.4. Effect of Welding

When Ni-Cu 400 alloy was welded with filler metal 60 by the TIG welding process, the weld beads were severely pitted both in the seawater and in the bottom sediment after exposure for 402 days at a depth of 2,500 feet, but they were corroded uniformly after 181 days of exposure at the surface. Butt welds in Ni-Cu 400 alloy made by the manual shielded metal-arc process with electrode 190 were attacked by incipient pitting corrosion both in the seawater and in the bottom sediment after 189 days of exposure at a depth of 5,900 feet and by crater corrosion of the weld bead after 540 days of exposure at the surface. Three-inch-diameter, unrelieved, circular welds in Ni-Cu 400 alloy by the manual shielded metal-arc process with electrode 190 corroded uniformly both in the seawater and in the bottom sediment after 189 days of exposure at a depth of 5,900 feet. The unrelieved circular welds were tested to determine whether welding stresses would cause any corrosion-induced cracking. When Ni-Cu 400 alloy was welded by the manual shielded metal-arc process with electrodes 130 and 180, the weld beads were corroded uniformly after 181 days of exposure at the surface and after 402 days of exposure at the 2,500-foot depth. There was no preferential corrosion when Ni-Cu 400 was TIG welded with electrode 167 after 402 days of exposure at the 2,500-foot depth, but the weld bead was selectively attacked and was covered with a deposit of copper after 403 days of exposure at the 6,000-foot depth [7].

The weld beads in Ni-Cu K-500 alloy made by the manual shielded metal-arc process with electrode 134 were attacked by pitting corrosion of the weld bead and the heat-affected zone after 181 days of exposure at the surface, by crater corrosion of the weld bead after 540 days of exposure at the surface, and by line corrosion at the edge of the weld bead after 402 days of exposure at the 2,500-foot depth. When Ni-Cu K-500 alloy was TIG welded with filler metal 64, the weld beads were uniformly corroded after 181 days of exposure at the surface and 402 days of exposure at the 2,500-foot depth, and the weld beads and the heat-affected zones were attacked by pitting corrosion after 540 days of exposure at the surface.

4.2.5. Galvanic Corrosion

When AISI 4130 steel was fastened to Ni-Cu 400 alloy in a surface area ratio of 1:2, the AISI 4130 was severely corroded and the Ni-Cu 400 was uncorroded after 403 days of exposure at the 6,000-foot depth [7]. This shows that the steel was being sacrificed to protect the nickel- copper alloy.

4.2.6. Crevice Corrosion

Ni-Cu 400 alloy hardware was attacked by crevice corrosion after 751 days of exposure at the 6,000-foot depth when in contact with fiberglass [13].

4.2.7. Corrosion Products

X-ray diffraction, spectrochemical, and chemical analyses of corrosion products removed from nickel-copper alloys 400 and K-500 showed that they were composed of cupric oxide (CuO), nickel oxide (NiO), nickel hydroxide ($Ni(OH)_2$), cupric chloride ($CuCl_2$), copper- oxy-chloride ($CuCl_2;3CuO;4H_2O$), a trace of nickel sulfide (NiS), and phosphate, chloride, and sulfate ions.

4.2.8. Mechanical Properties

The effects of exposure on the mechanical properties of Ni-Cu 400 and K-500 alloys are shown in Table 31. There were no significant changes due to corrosion of either unwelded or welded alloys.

4.3. NICKEL ALLOYS

The chemical compositions of the nickel alloys are given in Table 32, their corrosion rates and types of corrosion in Table 33, and the changes in their mechanical properties due to corrosion in Table 34.

There were no significant weight losses (none greater than 0.1 mpy) or any visible corrosion on any of the following alloys:

Ni-Cr-Fe 718, unwelded and welded

Ni-Cr-Mo 625, unwelded and welded

Ni-Mo-Cr C and 3

Ni-Cr-Fe-Mo F and G

Ni-Cr-Co 41

There were no significant weight losses (none greater than 0.1 mpy) and only some cases of incipient crevice corrosion on the following alloys:

Ni-Fe-Cr 804, 825Cb, and 901

Ni-Co-Cr 700

Ni-Cr-Fe-Mo X

The corrosion resistance of Ni-Fe-Cr 825Cb was better than that of its counterparts 825 and 825S (sensitized). Alloy 825 was attacked by both pitting and crevice corrosion, and 825S had only one case of crevice corrosion. Thus, the addition of small amounts of columbium to alloy 825 improves its corrosion resistance, at least in seawater.

All the nickel alloys corroded essentially the same in the bottom sediments as in the seawater above them.

4.3.1. Duration of Exposure

The corrosion rates and types of corrosion of the nickel alloys are given in Table 33. Except for the 12 alloys above, 13 of the remaining 16 alloys were attacked by crevice and pitting corrosion with crevice corrosion being considerably more predominant. Ni-Be alloy was attacked by pitting corrosion on the ends of the bars. Ni-Mo-Fe alloys B and 2 were attacked by general corrosion. Because of the crevice and pitting types of corrosion, corrosion rates were meaningless for determining effects of duration of exposure on the corrosion behavior of these alloys. These 14 alloys were: Ni-Cr-Fe alloys 600, 610, X-750, and 88, Ni-Fe-Cr alloys 800, 825, 825S, and 902, Ni-Sn-Zn 23, Ni-Cr alloys 65-35, 75, and 80-20, Ni-Si alloy D, and Ni-Be.

4.3.2. Effect of Depth

The severity and frequency of crevice and pitting corrosion, in general, of the 16 alloys given in the previous paragraph were much greater at the surface than at depth. Also, the average corrosion rates were greater at the surface than at depth, although they did not decrease progressively or constantly with increasing depth, as shown in Figure 16. Although these corrosion rates are unreliable because they are based upon localized corrosion weight losses, they do substantiate the conclusion based upon the frequency and severity of pitting and crevice corrosion.

4.3.3. Effect of Concentration of Oxygen

The severity and frequency of crevice and pitting corrosion of the nickel alloys which corroded significantly, in general, increased with increasing concentration of oxygen in seawater. Their average corrosion rates calculated from weight losses increased asymptotically with increasing concentration of oxygen, as shown in Figure 17.

4.3.4. Effect of Welding

The weld beads in Ni-Cr-Fe 600 alloy, made by the TIG welding process using filler metal 62, were perforated by line corrosion along their edges after 402 days of exposure at the 2,500-foot depth, and 540 days of exposure at the surface; the weld bead was attacked by incipient pitting corrosion after 181 days of exposure at the surface.

When Ni-Cr-Fe 600 alloy was TIG welded with filler metal 82, the weld beads and heat-affected zones were perforated after 402 days of exposure at the 2,500-foot depth; the weld bead was pitted after 540 days of exposure at the surface; and the weld bead was slightly etched after 181 days of exposure at the surface.

The weld beads in Ni-Cr-Fe 600 alloy, made by the manual shielded metal-arc process using electrode 132, were perforated after 402 days of exposure at the 2,500-foot depth and after 540 days of exposure at the surface. The weld beads were also attacked by tunnel corrosion after 540 days of exposure at the surface.

Weld beads in Ni-Cr-Fe 600 alloy, made by the manual shielded metal-arc process using electrode 182, were perforated after 181 days of exposure at the surface, but were only etched after 402 days of exposure at the 2,500-foot depth.

Butt welds in Ni-Cr-Fe 718 alloy, made by the TIG process using filler metal 718, were uncorroded after 189 days of exposure in both seawater and bottom sediment at the 6,000-foot depth, in seawater after 402 days of exposure at the 2,500-foot depth, and after 540 days of exposure at the surface. Also, 3-inch-diameter, unrelieved, circular weld beads made by the same process were etched after 189 days of exposure in seawater and in the bottom sediment at the 6,000-foot depth.

The weld beads in Ni-Cr-Fe X-750 alloy, made by the TIG process using filler metal 69, were etched after 402 days of exposure at the 2,500-foot depth, but both the weld beads and heat-affected zones were attacked by crater corrosion after 540 days of exposure at the surface. Weld beads in Ni-Cr-Fe X-750 alloy, made by the manual shielded metal-arc process, were perforated and the heat-affected zone was attacked by tunnel corrosion after 402 days of exposure at the 2,500-foot depth; the heat-affected zone was perforated by crater corrosion after 540 days of exposure at the surface.

Weld beads in Ni-Fe-Cr 800 alloy, made by the TIG process with filler metal 82, were perforated by line corrosion along their edges after 402 days of exposure at the 2,500-foot depth, and both the weld beads and heat-affected zones were attacked by tunnel corrosion after 540 days of exposure at the surface. There was line corrosion along the edge of the weld beads when Ni-Fe-Cr 800 alloy was welded by the manual shielded metal-arc process using electrode 138 after 402 days of exposure at the 2,500-foot depth. Both the weld beads and heat-affected zones were perforated by corrosion after 540 days of exposure at the surface when Ni-Fe-Cr 800 alloy was welded by the manual shielded metal-arc process using electrode 182.

Weld beads in Ni-Fe-Cr 825 alloy, made by the TIG welding process with filler metal 65, were uncorroded after 402 days of exposure at the 2,500-foot depth and after 181 days of exposure at the surface; the weld beads and heat-affected zones were attacked by incipient pitting corrosion after 540 days of exposure at the surface. When butt welds were made by the manual shielded metal-arc process using electrode 135, the weld beads were uncorroded after 181 days of exposure at the surface and 189 days of exposure in the bottom sediment at the 6,000-foot depth; there was incipient pitting of the weld bead after 189 days of exposure in the seawater at the 6,000-foot depth; one end of the weld bead was corroded after 402 days of exposure at the 2,500-foot depth; and there was crater corrosion of the heat-affected zone after 540 days of exposure at the surface. When the weld beads were 3-inch-diameter unrelieved circles made by the manual shielded metal-arc process, they were uncorroded after 189 days of exposure in seawater and in the bottom sediment at the 6,000-foot depth.

Butt welds and 3-inch-diameter, unrelieved circular welds in Ni-Cr-Mo 625 alloy, made by the TIG welding process using filler metal 625, were uncorroded after 189 days of exposure at the 6,000-foot depth and after 588 days of exposure at the surface.

4.3.5. Galvanic Corrosion

When AISI 4130 steel was fastened to Ni-Cr-Fe 600 alloy in a surface area ratio of 1:2, the 4130 was severely corroded and the Ni-Cr-Fe 600 alloy was uncorroded after 403 days of exposure at the 6,000-foot depth [7]. This shows that the 4130 steel was the anodic member of the couple and was being sacrificed to protect the cathodic nickel alloy. When Ni-Be alloy was fastened to Ni-Cr-Fe 600 alloy in a surface area ratio of 1:2, the Ni-Be was severely attacked with there being a much lesser amount of corrosion on the Ni-Cr-Fe 600 alloy.

4.3.6. Mechanical Properties

The effects of exposure on the mechanical properties of five of the nickel alloys are given in Table 34. The mechanical properties of Ni-Fe-Cr 825 and Ni-Mo-Cr C alloys were not affected. However, there were significant decreases in the elongations of alloys Ni-Cr-Fe 600, Ni-Fe-Cr 902, and Ni-Be,1/2HT.

4.4. STRESS CORROSION

The susceptibility of some of the nickel alloys to stress corrosion is given in Table 35. None of the alloys tested were susceptible to stress corrosion cracking at both the 2,500-foot and 6,000-foot depths for exposures of at least 400 days duration.

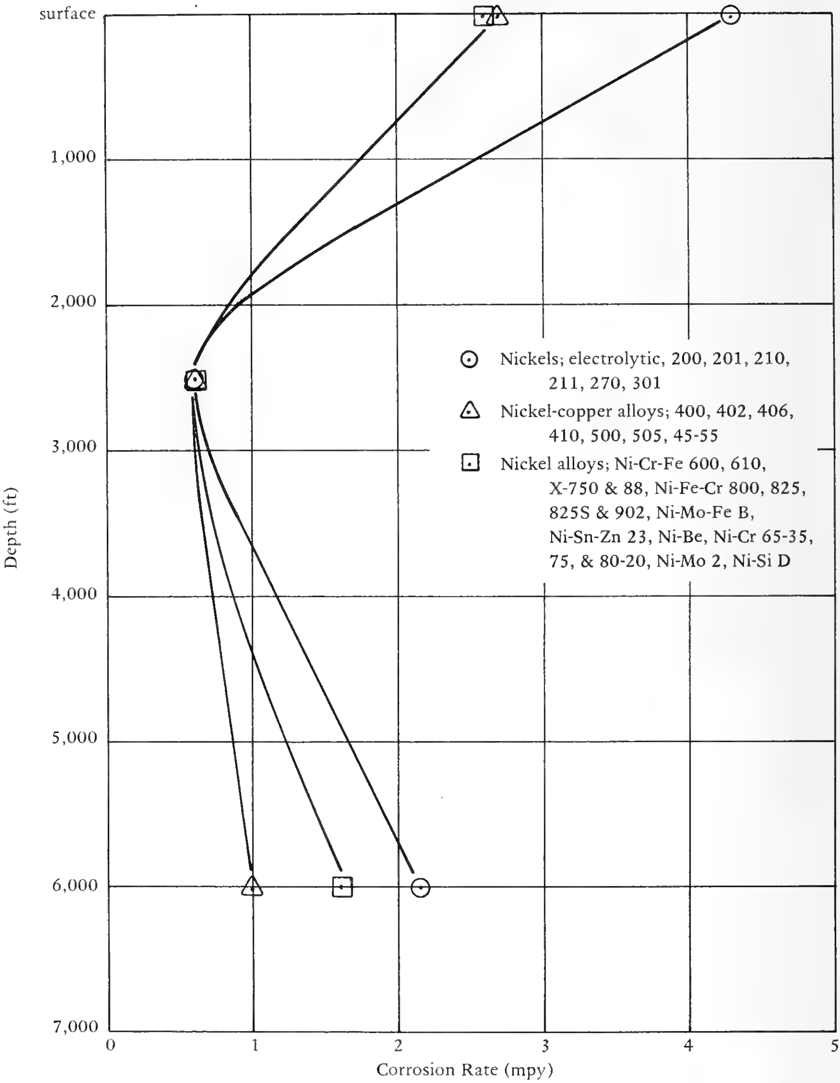

Figure 16. Effect of depth on the corrosion of nickel alloys after 1 year of exposure.

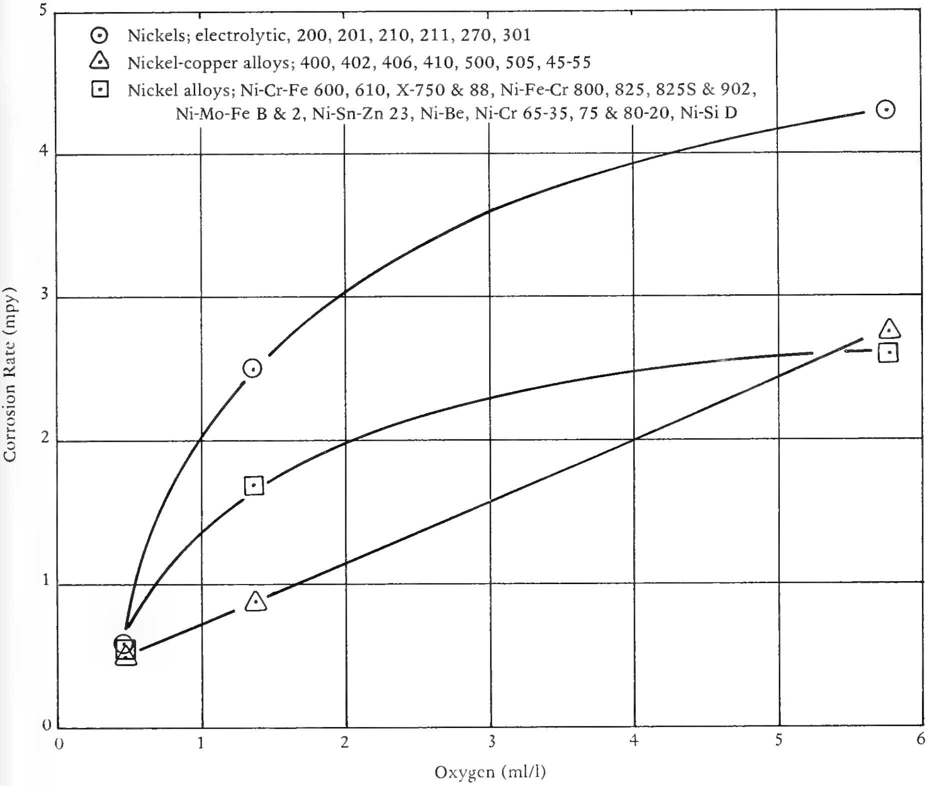

Figure 17. Effect of concentration of oxygen in seawater on the corrosion of nickel alloys after 1 year of exposure.

Table 26. Chemical Composition of Nickels, Percent by Weight

Alloy	Ni	C	Mn	Fe	S	Si	Cu	Ti	Other	Source[a]
Electrolytic Ni	99.97 + Co	–	–	–	–	–	–	–	–	INCO (3)
Ni-200	99.5	0.05	0.29	0.04	0.006	0.07	0.02	–	–	CEL (4)
Ni-200	99.5	0.06	0.25	0.15	0.005	0.05	0.05	–	–	CEL (4)
Ni-200	99.5	0.06	–	–	–	–	–	–	–	INCO (3)
Ni-201	99.5	0.01	–	–	–	–	–	–	–	INCO (3)
Ni-211	95.0	–	5.0	–	–	–	–	–	–	INCO (3)
Ni-270	99.97	–	–	–	–	–	–	–	–	INCO (3)
Ni-210, cast	95.6	–	1.0	–	–	2.0	–	–	–	INCO (3)
Ni-301	94.0	–	–	–	–	–	–	–	4.5 Al	INCO (3)
Filler metal 61	96.0	0.06	0.30	0.10	0.005	0.40	0.02	3.0	–	CEL (4)
Electrode 141	96.0	0.05	0.25	0.30	0.005	0.60	0.05	2.2	0.25 Al	CEL (4)

[a]Numbers refer to references at end of report.

Table 27. Corrosion Rates and Types of Corrosion of Nickels

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mil)	Crevice Depth (mil)	Type[b]	Weld[b]	
Electrolytic Ni	W	123	5,640	<0.1	–	3	C	–	INCO (3)
Electrolytic Ni	S	123	5,640	0.3	–	4	C	–	INCO (3)
Electrolytic Ni	W	403	6,780	1.2	–	20	C	–	INCO (3)
Electrolytic Ni	S	403	6,780	0.1	–	19	C	–	INCO (3)
Electrolytic Ni	W	751	5,640	0.5	–	50	C (PR)	–	INCO (3)
Electrolytic Ni	S	751	5,640	0.1	–	25	C	–	INCO (3)
Electrolytic Ni	W	1,064	5,300	0.7	50	–	P (PR)	–	INCO (3)
Electrolytic Ni	S	1,064	5,300	0.4	50	50	C (PR); P (PR)	–	INCO (3)
Electrolytic Ni	W	197	2,340	0.4	–	50	C (PR); P	–	INCO (3)
Electrolytic Ni	S	197	2,340	0.1	–	–	NU-ET	–	INCO (3)
Electrolytic Ni	W	402	2,370	0.6	–	50	C (PR)	–	INCO (3)
Electrolytic Ni	S	402	2,370	0.2	–	–	I-C; I-P	–	INCO (3)
Electrolytic Ni	W	181	5	4.5	30	30	C (PR); P (PR)	–	INCO (3)
Electrolytic Ni	W	366	5	6.9	30	30	C (PR); P (PR)	–	INCO (3)
Ni-200	W	123	5,640	0.7	–	SL	SL-C; EX-E[d]	–	CEL (4)
Ni-200	W	123	5,640	<0.1	–	2	C	–	INCO (3)
Ni-200	S	123	5,640	1.6	–	SL	SL-C; EX-E[d]	–	CEL (4)
Ni-200	S	123	5,640	0.3	–	22	C	–	INCO (3)
Ni-200	W	403	6,780	1.6	–	79	C; T (PR123)	–	CEL (4)
Ni-200	W	403	6,780	0.6	–	50	C (PR)	–	INCO (3)
Ni-200	S	403	6,780	1.7	–	29	C; T (PR123)	–	CEL (4)
Ni-200	S	403	6,780	0.4	38	–	P[e]	–	INCO (3)
Ni-200	W	751	5,640	1.8	–	116	C; T	–	CEL (4)
Ni-200	W	751	5,640	1.6	50	50	C (PR); P (PR)	–	INCO (3)
Ni-200	S	751	5,640	0.1	–	30	C; P	–	INCO (3)
Ni-200	W	1,064	5,300	1.2	–	8	C; EX-E[d]	–	CEL (4)
Ni-200	W	1,064	5,300	1.1	50	50	C (PR); P (PR)	–	INCO (3)
Ni-200	S	1,064	5,300	1.0	–	123	C (PR); EX-E[d]	–	CEL (4)
Ni-200	S	1,064	5,300	0.6	–	50	C (PR); EX-E[d]	–	INCO (3)
Ni-200	W	197	2,340	0.5	–	43	C; EX-E[d]	–	INCO (3)
Ni-200	W	197	2,340	0.5	–	10	C; P	–	INCO (3)

Continued

Table 27. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Corrosion Maximum Pit Depth (mil)	Corrosion Crevice Depth (mil)	Corrosion Type[b]	Corrosion Weld[b]	Source[c]
Ni-200	S	197	2,340	0.5	–	–	EX-E[d]	–	CEL (4)
Ni-200	S	197	2,340	<0.1	–	–	NU-ET	–	INCO (3)
Ni-200	W	402	2,370	0.6	–	3	C; S-ET	–	CEL (4)
Ni-200	W	402	2,370	0.6	–	50	C (PR)	–	INCO (3)
Ni-200, welded, electrode 141	W	402	2,370	0.8	–	–	ET; I-P	S-P	CEL (4)
Ni-200, welded, filler metal 61	W	402	2,370	0.6	–	–	ET; I-P	P (PR)	CEL (4)
Ni-200	S	402	2,370	0.5	–	–	U[f]	–	CEL (4)
Ni-200	S	402	2,370	0.2	–	–	I-C; I-P	–	INCO (3)
Ni-200, welded, filler metal 61	S	402	2,370	0.7	–	–	U[f]	–	INCO (3)
Ni-200	W	181	5	1.9	45	50	C; P	–	CEL (4)
Ni-200	W	181	5	7.2	50	50	C (PR); P (PR)	–	INCO (3)
Ni-200	W	366	5	4.5	40	40	C (PR); P (PR)	–	INCO (3)
Ni-200	W	398	5	1.9	125	–	P (PR); T	–	CEL (4)
Ni-200	W	540	5	1.5	125	–	P (PR); T	–	CEL (4)
Ni-200, welded, filler metal 61	W	540	5	1.9	125	–	P (PR); T	WB (PR); HAZ (PR)	CEL (4)
Ni-200	W	588	5	1.5	125	-	P (PR); T	–	CEL (4)
Ni-201	W	123	5,640	0.5	50	–	P (PR)	–	INCO (3)
Ni-201	S	123	5,640	1.3	50	–	P (PR)	–	INCO (3)
Ni-201	W	403	6,780	0.7	50	50	C (PR); P (PR)	–	INCO (3)
Ni-201	S	403	6,780	0.2	–	20	C	–	INCO (3)
Ni-201	W	751	5,640	1.1	30	30	C (PR); P (PR)	–	INCO (3)
Ni-201	S	751	5,640	0.2	30	30	C (PR); P (PR)	–	INCO (3)
Ni-201	W	1,064	5,300	0.8	50	50	C (PR); P (PR)	–	INCO (3)
Ni-201	S	1,064	5,300	0.3	50	50	C (PR); P (PR)	–	INCO (3)
Ni-201	W	197	2,340	0.5	–	50	C (PR); P[g]	–	INCO (3)
Ni-201	S	197	2,340	<0.1	–	–	I-C	–	INCO (3)
Ni-201	W	402	2,370	0.6	50	50	C (PR); P (PR)	–	INCO (3)
Ni-201	W	181	5	6.7	50	50	C (PR); P (PR)	–	INCO (3)
Ni-201	W	366	5	3.6	50	50	C (PR); P (PR)	–	INCO (3)
Ni-210, cast	W	123	5,640	2.0	8	–	P	–	INCO (3)
Ni-210, cast	S	123	5,640	1.1	23	–	P	–	INCO (3)
Ni-210, cast	W	403	6,780	7.2	–	70	C	–	INCO (3)
Ni-210, cast	S	403	6,780	0.3	–	–	U	–	INCO (3)
Ni-210, cast	W	751	5,640	3.3	–	75	C	–	INCO (3)

Continued

Table 27. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mil)	Crevice Depth (mil)	Type[b]	Weld[b]	
Ni-210, cast	S	751	5,640	1.7	–	67	C; P	–	INCO (3)
Ni-210, cast	W	1,064	5,300	1.5	50	–	P	–	INCO (3)
Ni-210, cast	S	1,064	5,300	0.9	12	16	C; P	–	INCO (3)
Ni-210, cast	W	197	2,340	0.6	–	–	I-C; I-P	–	INCO (3)
Ni-210, cast	S	197	2,340	<0.1	–	–	SL-ET	–	INCO (3)
Ni-210, cast	W	402	2,370	0.7	–	16	C	–	INCO (3)
Ni-210, cast	S	402	2,370	0.3	–	–	G	–	INCO (3)
Ni-210, cast	W	181	5	5.0	30	12	C; P	–	INCO (3)
Ni-210, cast	W	366	5	3.4	68	32	C; P	–	INCO (3)
Ni-211	W	123	5,640	0.3	–	22	C	–	INCO (3)
Ni-211	S	123	5,640	0.8	–	28	C; P	–	INCO (3)
Ni-211	W	403	6,780	0.8	50	50	C (PR); P (PR)	–	INCO (3)
Ni-211	S	403	6,780	0.2	–	29	C	–	INCO (3)
Ni-211	W	751	5,640	1.3	–	30	C (PR)	–	INCO (3)
Ni-211	S	751	5,640	0.3	–	30	C (PR)	–	INCO (3)
Ni-211	W	1,064	5,300	1.0	50	50	C (PR); P (PR)	–	INCO (3)
Ni-211	S	1,064	5,300	0.7	50	50	C (PR); P (PR)	–	INCO (3)
Ni-211	W	197	2,340	0.5	–	32	C (PR)	–	INCO (3)
Ni-211	S	197	2,340	<0.1	–	–	I-C	–	INCO (3)
Ni-211	W	402	2,370	0.6	–	50	C (PR)	–	INCO (3)
Ni-211	S	402	2,370	0.2	–	–	I-C; I-P	–	INCO (3)
Ni-211	W	181	5	5.0	50	50	C (PR); P (PR)	–	INCO (3)
Ni-211	W	366	5	4.5	50	50	C (PR); P (PR)	–	INCO (3)
Ni-270	W	402	2,370	0.6	–	50	C (PR)	–	INCO (3)
Ni-270	S	402	2,370	0.3	–	–	I-C; I-P	–	INCO (3)
Ni-270	W	181	5	6.5	10	21	C; P	–	INCO (3)
Ni-270	W	366	5	4.5	40	40	C (PR); P (PR)	–	INCO (3)
Ni-301	W	123	5,640	2.8	–	50	C (PR)	–	INCO (3)
Ni-301	S	123	5,640	3.1	–	50	C (PR)	–	INCO (3)
Ni-301	W	403	6,780	4.1	–	50	C (PR)	–	INCO (3)
Ni-301	S	403	6,780	1.0	–	40	C (PR)	–	INCO (3)
Ni-301	W	751	5,640	3.3	–	50	C (PR)	–	INCO (3)
Ni-301	S	751	5,640	2.7	–	50	C (PR)	–	INCO (3)

Continued

Table 27. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mil)	Crevice Depth (mil)	Type[b]	Weld[b]	
Ni-301	W	1,064	5,300	1.8	–	50	C (PR)	–	INCO (3)
Ni-301	S	1,064	5,300	1.1	35	50	C (PR); P	–	INCO (3)
Ni-301	W	197	2,340	1.1	–	50	C (PR)	–	INCO (3)
Ni-301	S	197	2,340	<0.1	–	–	I-C	–	INCO (3)
Ni-301	W	402	2,370	0.7	–	–	SL-E	–	INCO (3)
Ni-301	S	402	2,370	0.2	–	35	C (PR)	–	INCO (3)
Ni-301	W	181	5	3.8	18	–	P	–	INCO (3)
Ni-301	W	366	5	4.1	40	40	C (PR); P (PR)	–	INCO (3)

[a]W = Totally exposed in seawater on sides of structure; S = Exposed in base of structure so that a portion of each specimen was embedded in the bottom sediments.

[b]Symbols for types of corrosion:

C	= Crevice	P	= Pitting
E	= Edge	PR	= Perforated
ET	= Etched	S	= Severe
EX	= Extensive	SL	= Slight
G	= General	T	= Tunnel
HAZ	= Heat affected zone	U	= Uniform
I	= Incipient	V	= Very
NC	= No visible corrosion	W	= Weld bead
NU	= Nonuniform		

Numbers indicate maximum depth in mils.

[c]Numbers refer to references at end of report.

[d]Sheared edges only.

[e]One pit only.

[f]Portion in sediment bright, uncorroded.

[g]Elongated pits.

Table 28. Changes in Mechanical Properties of Nickel-200 Due to Corrosion

Alloy	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[a]
			Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
Ni-200	123	5,640	65	-1	18	-16	46	0	CEL (4)
Ni-200	403	6,780	65	+2	18	+1	46	-1	CEL (4)
Ni-200	751	5,640	65	+1	18	+1	46	-4	CEL (4)
Ni-200	1,064	5,300	65	0	18	-10	46	-13	CEL (4)
Ni-200	197	2,340	65	0	18	-10	46	-4	CEL (4)
Ni-200	402	2,370	65	+1	18	+4	46	-5	CEL (4)
Ni-200	181	5	65	+1	18	+10	46	-4	CEL (4)

[a]Numbers refer to references at end of report.

Table 29. Chemical Composition of Nickel-Copper Alloys, Percent by Weight

Alloy	Ni	Cu	C	Mn	Fe	S	Si	Ti	Other	Source[a]
Ni-Cu 400	65.17	32.62	0.11	1.06	0.90	0.007	0.10	–	–	CEL (4)
Ni-Cu 400	66.00	31.50	0.12	0.90	1.35	0.005	0.15	–	–	CEL (4)
Ni-Cu 400	68.02	29.25	0.12	0.99	1.52	0.010	<0.05	–	<0.10 Al	CEL (4)
Ni-Cu 400	65.90	31.75	0.14	0.94	1.07	0.010	0.19	–	<0.10 Al	CEL (4)
Ni-Cu 400	66.00	32.00	–	0.90	1.40	–	0.20	–	–	INCO (3)
Filler metal 60	66.00	30.50	0.03	0.35	0.10	0.005	0.50	2.20	–	CEL (4)
Electrode 130	68.00	27.00	0.15	2.50	0.50	0.005	0.40	0.30	1.00 Al	CEL (4)
Electrode 180	63.00	28.00	0.03	5.00	0.25	0.005	0.75	0.70	0.30 Al 1.50 Cb	CEL (4)
Ni-Cu 402	58.00	40.00	–	0.90	1.20	–	0.10	–	–	INCO (3)
Ni-Cu 406	84.00	13.00	–	0.90	1.40	–	0.20	–	–	INCO (3)
Ni-Cu 410[b]	66.00	31.00	–	0.80	1.00	–	1.60	–	–	INCO (3)
Ni-Cu K-500	65.00	29.50	0.15	0.60	1.00	0.005	0.15	0.50	2.80 Al	CEL (4)
Ni-Cu K-500	65.00	30.00	–	0.60	1.00	–	0.20	–	2.80 Al	INCO (3)
Ni-Cu 505[b]	64.00	29.00	–	0.80	2.00	–	4.00	–	–	INCO (3)
Filler metal 64	65.00	29.50	0.15	0.60	1.00	0.005	0.15	0.50	2.80 Al	CEL (4)
Electrode 134	66.00	27.00	0.25	2.50	1.00	0.005	0.40	0.30	2.00 Al	CEL (4)
Ni-Cu 60	65.00	30.00	–	0.90	2.00	–	1.00	–	1.00 Al	INCO (3)

[a]Numbers refer to references at end of report.

[b]Cast alloy.

Table 30. Corrosion Rates and Types of Corrosion of the Nickel-Copper Alloys

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mil)	Crevice Depth (mil)	Type[b]	Weld[b]	
Ni-Cu 400	W	123	5,640	0.8	–	–	U	–	CEL (4)
Ni-Cu 400	W	123	5,640	0.4	–	–	U	–	INCO (3)
Ni-Cu 400	W	123	5,640	0.5	–	–	ET; I-C	–	MEL (5)
Ni-Cu 400	S	123	5,640	0.5	–	–	U	–	CEL (4)
Ni-Cu 400	S	123	5,640	0.4	–	5	C; U	–	INCO (3)
Ni-Cu 400	W	189	5,900	0.4	–	5	C; I-P	–	CEL (4)
Ni-Cu 400	S	189	5,900	0.3	1	–	I-C; I-P	–	CEL (4)
Ni-Cu 400, long. butt weld, electrode 190	W	189	5,900	0.4	–	–	I-P	I-P	CEL (4)
Ni-Cu 400, long. butt weld, electrode 190	S	189	5,900	0.4	–	–	I-P	I-P	CEL (4)
Ni-Cu 400, 3-in. circular weld, electrode 190	W	189	5,900	0.3	–	–	U	U	CEL (4)
Ni-Cu 400, 3-in. circular weld, electrode 190	S	189	5,900	0.3	–	–	U	U	CEL (4)
Ni-Cu 400	W	403	6,780	0.5	20	10	C; P; E	–	CEL (4)
Ni-Cu 400	W	403	6,780	0.8	–	40	C (PR); U	–	INCO (3)
Ni-Cu 400	S	403	6,780	0.4	18	10	C; P; E	–	CEL (4)
Ni-Cu 400	S	403	6,780	0.1	–	2	C; U	–	INCO (3)
Ni-Cu 400	W	751	5,640	1.0	45	45	C; P; E	–	CEL (4)
Ni-Cu 400	W	751	5,640	3.1	–	40	C (PR); P	–	INCO (3)
Ni-Cu 400	W	751	5,640	0.1	–	13	C; ET	–	MEL (5)
Ni-Cu 400	S	751	5,640	1.3	–	40	C (PR)	–	INCO (3)
Ni-Cu 400	W	1,064	5,300	0.8	–	6	C; E	–	CEL (4)
Ni-Cu 400	W	1,064	5,300	0.5	–	40	C (PR); P	–	INCO (3)
Ni-Cu 400	S	1,064	5,300	0.6	47	125	C (PR); P	–	CEL (4)
Ni-Cu 400	S	1,064	5,300	0.6	–	40	C (PR); CR	–	INCO (3)
Ni-Cu 400	W	197	2,340	0.4	10	11	C; P	–	CEL (4)
Ni-Cu 400	W	197	2,340	0.4	–	7	C	–	INCO (3)
Ni-Cu 400	W	197	2,340	1.0	–	–	U	–	NADC (7)
Ni-Cu 400	S	197	2,340	0.3	–	–	U	–	CEL (4)
Ni-Cu 400	S	197	2,340	0.2	–	4	C	–	INCO (3)
Ni-Cu 400	W	402	2,370	0.4	20	–	P	–	CEL (4)
Ni-Cu 400	W	402	2,370	0.8	–	40	C (PR); P	–	INCO (3)
Ni-Cu 400	S	402	2,370	0.3	–	–	E; I-P	–	CEL (4)
Ni-Cu 400	S	402	2,370	0.1	–	–	ET	–	INCO (3)
Ni-Cu 400, welded, electrode 130	W	402	2,370	0.5	–	–	I-P	U	CEL (4)
Ni-Cu 400, welded, electrode 180	W	402	2,370	0.5	–	–	I-P	U	CEL (4)
Ni-Cu 400, welded, filler metal 60	W	402	2,370	0.4	–	–	I-P	S-P	CEL (4)

Continued

Table 30. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mil)	Crevice Depth (mil)	Type[b]	Weld[b]	
Ni-Cu 400, welded, filler metal 60	S	402	2,370	0.4	–	–	E	S-P	CEL (4)
Ni-Cu 400	W	181	5	0.6	28	15	C; P	–	CEL (4)
Ni-Cu 400	W	181	5	5.8	12	40	C (PR); P	–	INCO (3)
Ni-Cu 400, welded, electrode 180	W	181	5	0.7	11	–	P	U	CEL (4)
Ni-Cu 400, welded, filler metal 60	W	181	5	0.5	12	–	P	U	CEL (4)
Ni-Cu 400	W	366	5	2.4	16	40	C (PR); P	–	INCO (3)
Ni-Cu 400	W	386[d]	5	1.3	20	63	C (PR); P	–	MEL (5)
Ni-Cu 400	W	398	5	0.8	39	–	P	–	CEL (4)
Ni-Cu 400	W	540	5	0.9	17	–	P; E	–	CEL (4)
Ni-Cu 400, welded, electrode 190	W	540	5	1.2	28	–	P; CR	WB (CR)	CEL (4)
Ni-Cu 400	W	588	5	0.8	29	–	P	–	CEL (4)
Ni-Cu 402	W	123	5,640	0.3	–	–	U	–	INCO (3)
Ni-Cu 402	S	123	5,640	0.3	–	–	U	–	INCO (3)
Ni-Cu 402	W	403	6,780	0.7	–	–	U	–	INCO (3)
Ni-Cu 402	S	403	6,780	1.3	–	–	I-C	–	INCO (3)
Ni-Cu 402	W	751	5,640	0.5	–	14	C; P	–	INCO (3)
Ni-Cu 402	S	751	5,640	0.3	–	7	C	–	INCO (3)
Ni-Cu 402	W	1,064	5,300	0.3	–	12	C	–	INCO (3)
Ni-Cu 402	S	1,064	5,300	1.0	–	50	C (PR); CR	–	INCO (3)
Ni-Cu 402	W	197	2,340	0.4	–	–	U	–	INCO (3)
Ni-Cu 402	S	197	2,340	<0.1	–	–	I-C	–	INCO (3)
Ni-Cu 402	W	402	2,370	0.7	–	32	C (PR); P	–	INCO (3)
Ni-Cu 402	S	402	2,370	<0.1	–	–	I-C	–	INCO (3)
Ni-Cu 402	W	181	5	3.6	9	13	C; P	–	INCO (3)
Ni-Cu 402	W	366	5	2.3	30	30	C (PR); P (PR)	–	INCO (3)
Ni-Cu 406	W	123	5,640	0.2	–	8	C	–	INCO (3)
Ni-Cu 406	S	123	5,640	0.4	–	50	C (PR)	–	INCO (3)
Ni-Cu 406	W	403	6,780	0.5	–	50	C (PR)	–	INCO (3)
Ni-Cu 406	S	403	6,780	<0.1	–	–	I-C	–	INCO (3)
Ni-Cu 406	W	751	5,640	0.7	–	40	C (PR)	–	INCO (3)
Ni-Cu 406	S	751	5,640	0.3	–	40	C (PR)	–	INCO (3)
Ni-Cu 406	W	1,064	5,300	0.8	–	50	C (PR)	–	INCO (3)
Ni-Cu 406	S	1,064	5,300	1.0	–	50	C (PR)	–	INCO (3)
Ni-Cu 406	W	197	2,340	0.5	–	23	C	–	INCO (3)

Continued

Table 30. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mil)	Crevice Depth (mil)	Type[b]	Weld[b]	
Ni-Cu 406	S	197	2,340	<0.1	–	–	U-ET	–	INCO (3)
Ni-Cu 406	W	402	2,370	0.6	–	50	C (PR)	–	INCO (3)
Ni-Cu 406	S	402	2,370	0.1	–	30	C	–	INCO (3)
Ni-Cu 406	W	181	5	7.5	50	50	C (PR); P (PR)	–	INCO (3)
Ni-Cu 406	W	366	5	6.0	50	50	C (PR); P (PR)	–	INCO (3)
Ni-Cu 410, cast	W	123	5,640	0.8	–	–	U	–	INCO (3)
Ni-Cu 410, cast	S	123	5,640	0.5	–	–	U	–	INCO (3)
Ni-Cu 410, cast	W	403	6,780	1.1	–	–	U	–	INCO (3)
Ni-Cu 410, cast	S	403	6,780	<0.1	–	–	EBSL	–	INCO (3)
Ni-Cu 410, cast	W	751	5,640	0.9	–	–	U	–	INCO (3)
Ni-Cu 410, cast	S	751	5,640	0.5	–	–	U	–	INCO (3)
Ni-Cu 410, cast	W	1,064	5,300	0.5	–	–	G	–	INCO (3)
Ni-Cu 410, cast	S	1,064	5,300	0.4	–	–	G	–	INCO (3)
Ni-Cu 410, cast	W	197	2,340	0.6	–	–	U	–	INCO (3)
Ni-Cu 410, cast	S	197	2,340	0.2	–	–	U	–	INCO (3)
Ni-Cu 410, cast	W	402	2,370	0.4	–	–	G	–	INCO (3)
Ni-Cu 410, cast	S	402	2,370	0.1	–	–	I-P	–	INCO (3)
Ni-Cu 410, cast	W	181	5	1.3	16	14	C; P	–	INCO (3)
Ni-Cu 410, cast	W	366	5	3.1	19	30	C; P	–	INCO (3)
Ni-Cu K-500	W	123	5,640	0.4	–	9	C	–	INCO (3)
Ni-Cu K-500	W	123	5,640	0.7	–	11	ET; C	–	MEL (5)
Ni-Cu K-500	S	123	5,640	0.7	–	11	C	–	INCO (3)
Ni-Cu K-500	W	187	5,900	0.1	9	16	C; P	–	CEL (4)
Ni-Cu K-500	S	187	5,900	0.2	11	26	C; P	–	CEL (4)
Ni-Cu K-500	W	403	6,780	0.3	–	18	C	–	INCO (3)
Ni-Cu K-500	S	403	6,780	<0.1	–	2	C	–	INCO (3)
Ni-Cu K-500	W	751	5,640	3.6	–	30	C (PR)	–	INCO (3)
Ni-Cu K-500	W	751	5,640	0.4	8	63	C (PR); P (PR)	–	MEL (5)
Ni-Cu K-500	S	751	5,640	1.5	–	30	C (PR)	–	INCO (3)
Ni-Cu K-500	W	1,064	5,300	0.9	–	30	C (PR)	–	INCO (3)
Ni-Cu K-500	S	1,064	5,300	0.7	–	–	CR (PR30)	–	INCO (3)
Ni-Cu K-500	W	197	2,340	0.4	–	–	U	–	INCO (3)
Ni-Cu K-500	S	197	2,340	0.2	–	–	U	–	INCO (3)
Ni-Cu K-500	W	402	2,370	0.6	38	46	C; P	–	CEL (4)

Continued

Table 30. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion: Rate (mpy)	Corrosion: Maximum Pit Depth (mil)	Corrosion: Crevice Depth (mil)	Corrosion: Type[b]	Corrosion: Weld[b]	Source[c]
Ni-Cu K-500	W	402	2,370	0.6	–	30	C (PR)	–	INCO (3)
Ni-Cu K-500	W	402	2,370	0.6	–	30	C	–	Shell (9)
Ni-Cu K-500	S	402	2,370	0.3	–	7	C	–	Shell (9)
Ni-Cu K-500	S	402	2,370	0.3	48	37	C; P	–	CEL (4)
Ni-Cu K-500	S	402	2,370	<0.1	–	–	ET	–	INCO (3)
Ni-Cu K-500, welded, electrode 134	W	402	2,370	0.6	14	–	P	U[e]	CEL (4)
Ni-Cu K-500, welded, electrode 64	W	402	2,370	0.5	21	–	P	U	CEL (4)
Ni-Cu K-500	W	181	5	1.0	8	12	C; P	–	CEL (4)
Ni-Cu K-500	W	181	5	6.4	30	30	C (PR); P (PR)	–	INCO (3)
Ni-Cu K-500, welded, electrode 134	W	181	5	0.9	12	–	P	P (HAZ)(WB)	CEL (4)
Ni-Cu K-500, welded, filler metal 64	W	181	5	1.1	8	–	P	U	CEL (4)
Ni-Cu K-500	W	366	5	3.6	30	30	C (PR); P (PR)	–	INCO (3)
Ni-Cu K-500	W	386[d]	5	1.4	33	63	C (PR); P	–	MEL (5)
Ni-Cu K-500, welded, electrode 134	W	540	5	1.1	20	–	P	WB (CR)	CEL (4)
Ni-Cu K-500, welded, filler metal 64	W	540	5	0.9	13	–	P	P (WB)(HAZ)	CEL (4)
Ni-Cu 505, cast	W	123	5,640	1.4	–	–	U	–	INCO (3)
Ni-Cu 505, cast	S	123	5,640	2.4	–	–	U	–	INCO (3)
Ni-Cu 505, cast	W	403	6,780	1.9	–	–	U	–	INCO (3)
Ni-Cu 505, cast	S	403	6,780	<0.1	–	–	I-C	–	INCO (3)
Ni-Cu 505, cast	W	751	5,640	1.0	–	–	U	–	INCO (3)
Ni-Cu 505, cast	S	751	5,640	2.1	–	–	U	–	INCO (3)
Ni-Cu 505, cast	W	1,064	5,300	1.0	–	–	G	–	INCO (3)
Ni-Cu 505, cast	S	1,064	5,300	0.5	–	–	G	–	INCO (3)
Ni-Cu 505, cast	W	197	2,340	0.3	–	–	U	–	INCO (3)
Ni-Cu 505, cast	S	197	2,340	0.2	–	–	U	–	INCO (3)
Ni-Cu 505, cast	W	402	2,370	0.3	–	–	G	–	INCO (3)
Ni-Cu 505, cast	S	402	2,370	<0.1	–	–	ET	–	INCO (3)
Ni-Cu 505, cast	W	181	5	0.7	–	–	NU	–	INCO (3)
Ni-Cu 505, cast	W	366	5	1.1	13	–	P	–	INCO (3)
Ni-Cu 60	W	123	5,640	3.0	–	50	C (PR)	–	INCO (3)
Ni-Cu 60	S	123	5,640	2.1	–	24	C	–	INCO (3)
Ni-Cu 60	W	403	6,780	3.0	–	50	C (PR)	–	INCO (3)
Ni-Cu 60	S	403	6,780	<0.1	–	–	I-C	–	INCO (3)
Ni-Cu 60	W	751	5,640	4.9	–	62	C (PR)	–	INCO (3)

Continued

Table 30. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mil)	Crevice Depth (mil)	Type[b]	Weld[b]	
Ni-Cu 60	S	751	5,640	1.3	–	62	C (PR)	–	INCO (3)
Ni-Cu 60	W	1,064	5,300	1.4	–	62	C (PR)	–	INCO (3)
Ni-Cu 60	S	1,064	5,300	0.9	–	33	C; CR	–	INCO (3)
Ni-Cu 60	W	197	2,340	0.5	–	17	C	–	INCO (3)
Ni-Cu 60	S	197	2,340	0.1	–	–	U	–	INCO (3)

[a]W = Totally exposed in seawater on sides of structure; S = Exposed in base of structure so that the lower portions of the specimen were embedded in the bottom sediments.

[b]Symbols for types of corrosion:

C	= Crevice	I	= Incipient
CR	= Cratering	NU	= Nonuniform
E	= Edge	P	= Pitting
EBSL	= Etched below sediment line	PR	= Perforation
ET	= Etched	S	= Severe
G	= General	U	= Uniform
HAZ	= Heat affected zone	WB	= Weld bead

Numbers indicate maximum depth in mils.

[c]Numbers refer to References at end of report.

[d]Francis L. LaQue Corrosion Laboratory, INCO, Wrightsville Beach, N.C.

[e]Line corrosion at edge of weld bead.

Table 31. Changes in Mechanical Properties of Nickel-Copper Alloys Due to Corrosion

Alloy	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[a]
			Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
Ni-Cu 400	123	5,640	75	+2	29	+1	44	+1	CEL (4)
Ni-Cu 400	403	6,780	75	+2	29	+2	44	+2	CEL (4)
Ni-Cu 400	751	5,640	75	-2	29	-2	44	-22	CEL (4)
Ni-Cu 400	1,064	5,300	75	+3	29	+5	44	-3	CEL (4)
Ni-Cu 400	197	2,340	75	+2	29	+1	44	-1	CEL (4)
Ni-Cu 400	197	2,340	82	0	41	+11	40	-14	NADC (7)
Ni-Cu 400	402	2,370	82	-1	41	-2	40	-25	NADC (7)
Ni-Cu 400	402	2,370	75	+3	29	+6	44	-1	CEL (4)
Ni-Cu 400	402	2,370	77	0	29	0	44	0	CEL (4)
Ni-Cu 400, welded, filler metal 60	402	2,370	77	-3	29	+17	44	-34[b]	CEL (4)
Ni-Cu 400, welded, filler metal 60[c]	402	2,370	77	+1	29	+14	44	-26[b]	CEL (4)
Ni-Cu 400, welded, electrode 130	402	2,370	77	0	29	+14	44	-15[b]	CEL (4)
Ni-Cu 400, welded, electrode 180	402	2,370	77	0	29	+16	44	-25[b]	CEL (4)
Ni-Cu 400	181	5	75	+2	29	+1	44	-11	CEL (4)
Ni-Cu K-500	402	2,370	98	+1	43	+4	37	+1	CEL (4)

[a] Numbers refer to references at end of report.

[b] Broke in weld.

[c] Partially embedded in bottom sediment.

Table 32. Chemical Composition of Other Nickel Alloys, Percent by Weight

Alloy	Ni	C	Mn	Fe	S	Si	Cu	Cr	Ti	Mo	Cb	Other	Source[a]
Ni-Cr-Fe 600	76.00	0.04	0.20	7.20	0.007	0.20	0.10	15.8	–	–	–	–	CEL (4)
Ni-Cr-Fe 600	75.26	0.06	0.18	7.25	0.008	0.27	0.38	16.0	–	–	–	–	CEL (4)
Ni-Cr-Fe 600	76.0	–	–	7.0	–	–	–	16.0	–	–	–	–	INCO (3)
Ni-Cr-Fe 610	71.0	–	–	9.0	–	2.0	–	16.0	–	–	–	–	INCO (3)
Ni-Cr-Fe 718	52.5	0.04	0.20	18.0	0.007	0.20	0.10	19.0	0.80	3.0	5.2	0.60 Al	CEL (4)
Ni-Cr-Fe X750	73.41	0.08	0.55	6.90	0.003	0.36	0.09	14.50	2.40	–	0.90	0.81 Al	CEL (4)
Ni-Cr-Fe X750	73.0	–	–	7.0	–	–	–	15.0	2.5	–	–	–	INCO (3)
Ni-Cr-Fe X750	73.0	0.04	0.70	6.75	0.007	0.30	0.05	15.0	2.50	–	0.85	0.80 Al	CEL (4)
Ni-Fe-Cr 800	32.0	–	1.0	46.0	–	–	–	20.0	–	–	–	–	INCO (3)
Ni-Fe-Cr 800	32.0	0.04	0.75	46.0	0.007	0.35	0.30	20.5	–	–	–	–	CEL (4)
Ni-Fe-Cr 804	43.0	–	–	25.0	–	–	–	29.0	–	–	–	–	INCO (3)
Ni-Fe-Cr 825	41.12	0.05	0.82	30.86	0.01	0.31	1.61	21.12	1.00	2.94	–	0.14 Al	CEL (4)
Ni-Fe-Cr 825	41.8	0.03	0.65	30.0	0.007	0.35	1.80	21.5	0.90	3.0	–	0.15 Al	CEL (4)
Ni-Fe-Cr 825	42.0	–	–	30.0	–	–	2.0	22.0	–	3.0	–	–	INCO (3)
Ni-Fe-Cr 825Cb	42.0	–	–	30.0	–	–	2.0	22.0	–	3.0	–	–	INCO (3)
Ni-Fe-Cr 901	43.0	–	–	34.0	–	–	–	14.0	–	–	–	–	INCO (3)
Ni-Fe-Cr 902	42.0	0.02	0.40	48.5	0.008	0.50	0.05	5.4	2.40	–	–	0.65 Al	CEL (4)
Ni-Cr-Mo 103[c]	67.0	0.02	–	–	–	–	–	18.0	–	14.0	0.5	–	CEL (4)
Ni-Cr-Mo 625	61.0	0.05	0.15	3.00	0.007	0.30	0.10	22.0	–	9.0	4.0	–	CEL (4)
Ni-Cr-Mo 625	63.0	–	–	–	–	–	–	22.0	–	9.0	–	–	INCO (3)
Ni-Mo-Cr "C"	55.68	0.05	0.52	6.32	0.009	0.62	–	15.33	–	16.71	–	3.53 W 0.96 Co 0.26 V 0.010 P	CEL (4)
Ni-Mo-Cr "C"	60.0	–	–	5.0	–	–	–	15.0	–	16.0	–	4.0 W	INCO (3)
Ni-Mo-Cr 3	58.0	–	–	3.00	–	–	–	19.0	–	19.0	–	–	INCO (3)
Ni-Co-Cr 700	46.0	–	–	1.0	–	–	–	15.0	–	3.75	–	28.5 Co 3.0 Al	INCO (3)
Ni-Cr-Co "41"	55.29	0.11	<0.01	0.33	–	0.07	–	19.08	3.34	9.72	–	11.47 Co	CEL (4)
Ni-Mo-Fe "B"	60.0	–	–	5.0	–	–	–	–	–	26.0	–	–	INCO (3)
Ni-Mo-Fe 2	66.0	–	–	2.0	–	–	–	–	–	30.0	–	–	INCO (3)
Ni-Co-Cr-Mo[b]	35.0	–	–	–	–	–	–	19.84	–	10.0	–	35.0 Co	CEL (4)
Co-Cr-Ni-Fe-Mo[c]	14.96	0.05	1.96	14.60	–	0.74	–	19.84	–	7.14	–	0.058 Al 40.46 Co 0.07 Be	CEL (4)
Ni-Cr-Fe-Mo "F"	46.0	–	–	21.0	–	–	–	22.0	–	7.0	–	–	INCO (3)
Ni-Cr-Fe-Mo "G"	45.0	–	–	20.0	–	–	2.00	21.0	–	7.0	–	2.5 Co 1.0 W	INCO (3)
Ni-Cr-Fe-Mo "X"	60.0	–	–	19.0	–	–	–	22.0	–	9.0	–	–	INCO (3)
Ni-Cr-Fe 88	71.0	–	–	7.0	–	–	–	10.0	–	–	–	5.0 Sn 3.0 Bi	INCO (3)
Ni-Sn-Zn 23	79.0	–	2.0	–	–	–	–	–	–	–	–	8.0 Sn 7.0 Zn 4.0 Pb	INCO (3)
Ni-Be	97.55	–	–	–	–	–	–	–	–	–	–	1.95 Be	CEL (4)

Continued

Table 32. Continued.

Alloy	Ni	C	Mn	Fe	S	Si	Cu	Cr	Ti	Mo	Cb	Other	Source[a]
Ni-Cr 65-35	65.0	–	–	–	–	–	–	35.0	–	–	–	–	INCO (3)
Ni-Cr 75	78.0	–	–	–	–	–	–	20.0	–	–	–	–	INCO (3)
Ni-Cr 80-20	80.0	–	–	–	–	–	–	20.0	–	–	–	–	INCO (3)
Ni-Si "D"	86.0	–	–	–	–	10.0	3.0	–	–	–			INCO (3)
Filler metal 62	73.5	0.04	0.20	7.50	0.007	0.30	0.03	16.0	–	–	2.3	–	CEL (4)
Filler metal 65	42.0	0.03	0.80	30.0	0.008	0.30	1.70	21.0	0.90	3.0	–	–	CEL (4)
Filler metal 69	72.8	0.04	0.70	6.80	0.007	0.30	0.05	15.2	2.40	–	0.85	0.80 Al	CEL (4)
Filler metal 82	72.0	0.02	3.00	1.00	0.007	0.20	0.02	20.0	0.5	–	2.5	–	CEL (4)
Electrode 132	74.0	0.05	0.75	8.50	0.005	0.20	0.10	14.0	–	–	2.0	0.1 Ce	CEL (4)
Electrode 135	38.0	0.05	0.50	31.0	0.008	0.40	1.80	19.0	–	5.5	1.0	–	CEL (4)
Electrode 138	38.0	0.16	1.90	27.0	0.008	0.40	0.40	28.0	–	3.60	–	1.0 W	CEL (4)
Electrode 182	68.0	0.05	7.50	7.50	0.005	0.60	0.10	14.0	–	–	2.0	0.1 Ce	CEL (4)
Filler metal 718	52.5	0.04	0.20	18.0	0.007	0.20	0.10	19.0	0.80	3.0	–	–	CEL (4)

[a]Numbers refer to references at end of report.

[b]Wire rope and bolts.

[c]Wire rope.

Table 33. Corrosion Rates and Types of Corrosion of Nickel Alloys

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mil)	Crevice Depth (mil)	Type[b]	Weld[b]	
Ni-Cr-Fe 600	W	123	5,640	<0.1	–	4	C	–	INCO (3)
Ni-Cr-Fe 600	S	123	5,640	<0.1	–	3	C	–	INCO (3)
Ni-Cr-Fe 600	W	189	5,900	<0.1	–	39	C	–	CEL (4)
Ni-Cr-Fe 600	S	189	5,900	0.0	–	–	I-C	–	CEL (4)
Ni-Cr-Fe 600	W	403	6,780	0.1	–	23	C	–	INCO (3)
Ni-Cr-Fe 600	S	403	6,780	0.3	–	–	I-C	–	INCO (3)
Ni-Cr-Fe 600	W	751	5,640	<0.1	–	33	C	–	INCO (3)
Ni-Cr-Fe 600	S	751	5,640	<0.1	–	4	C; P	–	INCO (3)
Ni-Cr-Fe 600	W	1,064	5,300	0.1	–	35	C (PR)	–	INCO (3)
Ni-Cr-Fe 600	W	1,064	5,300	0.5	–	51	C; P	–	CEL (4)
Ni-Cr-Fe 600	S	1,064	5,300	<0.1	–	2	C	–	INCO (3)
Ni-Cr-Fe 600	W	197	2,340	0.2	–	15	C	–	INCO (3)
Ni-Cr-Fe 600	S	197	2,340	0.1	–	10	C	–	INCO (3)
Ni-Cr-Fe 600	W	402	2,370	0.0	–	–	SL-ET; I-P	–	CEL (4)
Ni-Cr-Fe 600	W	402	2,370	0.1	–	28	C	–	INCO (3)
Ni-Cr-Fe 600, welded, filler metal 62	W	402	2,370	0.4	–	–	U	WB (PR)[d]	CEL (4)
Ni-Cr-Fe 600, welded, filler metal 82	W	402	2,370	0.3	–	–	U	WB (PR); T (PR)(HAZ)[d]	CEL (4)
Ni-Cr-Fe 600, welded, electrode 132	W	402	2,370	0.3	–	–	ET	WB (PR)	CEL (4)
Ni-Cr-Fe 600, welded, electrode 182	W	402	2,370	<0.1	–	–	ET	ET	CEL (4)
Ni-Cr-Fe 600	S	402	2,370	0.1	–	–	ET; T (PR125)	–	CEL (4)
Ni-Cr-Fe 600	S	402	2,370	<0.1	–	–	I-C	–	INCO (3)
Ni-Cr-Fe 600	W	181	5	0.2	105	–	E; P[e]	–	CEL (4)
Ni-Cr-Fe 600	W	181	5	1.7	50	50	C (PR); P (PR)	–	INCO (3)
Ni-Cr-Fe 600, welded, filler metal 62	W	181	5	<0.1	–	–	U	I-P	CEL (4)
Ni-Cr-Fe 600, welded, filler metal 82	W	181	5	<0.1	–	–	U	SL-ET	CEL (4)
Ni-Cr-Fe 600, welded, electrode 182	W	181	5	1.3	–	–	U	WB (PR)	CEL (4)
Ni-Cr-Fe 600	W	366	5	0.6	50	50	C (PR); P (PR)	–	INCO (3)
Ni-Cr-Fe 600	W	540	5	0.5	67	–	P	–	CEL (4)

Continued

Table 33. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mil)	Crevice Depth (mil)	Type[b]	Weld[b]	
Ni-Cr-Fe 600, welded, filler metal 62	W	540	5	0.7	88	–	P	WB (PR125)	CEL (4)
Ni-Cr-Fe 600, welded, filler metal 82	W	540	5	0.6	77	–	P	P	CEL (4)
Ni-Cr-Fe 600, welded, electrode 132	W	540	5	0.9	60	–	P	WB (PR); T	CEL (4)
Ni-Cr-Fe 600, welded, electrode 182	W	540	5	0.9	50	–	P	WB (PR)	CEL (4)
Ni-Cr-Fe 610, cast	W	123	5,640	0.3	–	4	C	–	INCO (3)
Ni-Cr-Fe 610, cast	S	123	5,640	0.1	–	2	C	–	INCO (3)
Ni-Cr-Fe 610, cast	W	403	6,780	<0.1	–	–	I-C	–	INCO (3)
Ni-Cr-Fe 610, cast	S	403	6,780	0.1	–	–	I-C	–	INCO (3)
Ni-Cr-Fe 610, cast	W	751	5,640	0.6	–	83	C	–	INCO (3)
Ni-Cr-Fe 610, cast	S	751	5,640	0.3	–	5	C	–	INCO (3)
Ni-Cr-Fe 610, cast	W	1,064	5,300	0.9	–	–	I-P	–	INCO (3)
Ni-Cr-Fe 610, cast	S	1,064	5,300	<0.1	–	13	C	–	INCO (3)
Ni-Cr-Fe 610, cast	W	197	2,340	0.2	–	2	C	–	INCO (3)
Ni-Cr-Fe 610, cast	S	197	2,340	<0.1	–	3	C	–	INCO (3)
Ni-Cr-Fe 610, cast	W	402	2,370	0.3	–	18	C	–	INCO (3)
Ni-Cr-Fe 610, cast	S	402	2,370	<0.1	–	–	I-C	–	INCO (3)
Ni-Cr-Fe 610, cast	W	181	5	1.8	180	23	C; P(PR)	–	INCO (3)
Ni-Cr-Fe 610, cast	W	366	5	1.3	55	24	C; P	–	INCO (3)
Ni-Cr-Fe 718	W	189	5,900	0.0	–	–	NC	–	CEL (4)
Ni-Cr-Fe 718	S	189	5,900	<0.1	–	–	NC	–	CEL (4)
Ni-Cr-Fe 718, longitudinal butt weld, electrode 718	W	189	5,900	<0.1	–	–	NC	–	CEL (4)
Ni-Cr-Fe 718, longitudinal butt weld, electrode 718	S	189	5,900	<0.1	–	–	NC	–	CEL (4)
Ni-Cr-Fe 718, 3-in. circular weld, electrode 718	W	189	5,900	<0.1	–	–	NC	ET	CEL (4)
Ni-Cr-Fe 718, 3-in. circular weld, electrode 718	S	189	5,900	<0.1	–	–	NC	ET	CEL (4)
Ni-Cr-Fe 718	W	402	2,370	<0.1	–	–	NC	–	CEL (4)

Continued

Table 33. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion: Rate (mpy)	Corrosion: Maximum Pit Depth (mil)	Corrosion: Crevice Depth (mil)	Corrosion: Type[b]	Corrosion: Weld[b]	Source[c]
Ni-Cr-Fe 718, welded, electrode 718	W	402	2,370	0.0	–	–	NC	NC	CEL (4)
Ni-Cr-Fe 718	W	181	5	<0.1	–	–	NC	–	CEL (4)
Ni-Cr-Fe 718	W	540	5	0.0	–	–	NC	–	CEL (4)
Ni-Cr-Fe 718, welded, electrode 718	W	540	5	0.0	–	–	NC	NC	CEL (4)
Ni-Cr-Fe X750	W	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe X750	S	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe X750	W	403	6,780	0.2	–	35	C (PR)	–	INCO (3)
Ni-Cr-Fe X750	S	403	6,780	<0.1	–	3	C	–	INCO (3)
Ni-Cr-Fe X750	W	751	5,640	0.4	–	40	C (PR)	–	INCO (3)
Ni-Cr-Fe X750	S	751	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe X750	W	1,064	5,300	0.1	25	40	C (PR); P	–	INCO (3)
Ni-Cr-Fe X750	W	1,064	5,300	0.1	–	47	C	–	INCO (3)
Ni-Cr-Fe X750	S	1,064	5,300	<0.1	–	9	C	–	INCO (3)
Ni-Cr-Fe X750	W	197	2,340	0.4	–	18	C	–	INCO (3)
Ni-Cr-Fe X750	S	197	2,340	<0.1	–	7	C	–	INCO (3)
Ni-Cr-Fe X750	W	402	2,370	0.1	–	16	C	–	Shell (9)
Ni-Cr-Fe X750	W	402	2,370	0.1	–	17	C	–	INCO (3)
Ni-Cr-Fe X750	W	402	2,370	0.1	–	–	T	–	CEL (4)
Ni-Cr-Fe X750, welded, filler metal 69	W	402	2,370	0.3	–	–	ET	ET	CEL (4)
Ni-Cr-Fe X750, welded, electrode 718	W	402	2,370	0.2	–	–	U	T (HAZ55); WB; E (PR)	CEL (4)
Ni-Cr-Fe X750	S	402	2,370	0.4	–	16	C	–	Shell (9)
Ni-Cr-Fe X750	S	402	2,370	<0.1	–	4	C	–	INCO (3)
Ni-Cr-Fe X750	S	402	2,370	<0.1	–	–	ET	–	CEL (4)
Ni-Cr-Fe X750	W	181	5	1.4	50	50	C (PR); P (PR)	–	INCO (3)
Ni-Cr-Fe X750	W	366	5	0.9	50	50	C (PR); P (PR)	–	INCO (3)
Ni-Cr-Fe X750	W	540	5	0.3	130	130	C (PR); P (PR)	–	CEL (4)
Ni-Cr-Fe X750, welded, filler metal 69	W	540	5	0.5	130	–	P (PR)	CR (WB&HAZ)	CEL (4)
Ni-Cr-Fe X750, welded, electrode 718	W	540	5	0.5	130	130	C (PR); P (PR)	CR (PR; HAZ)	CEL (4)

Continued

Table 33. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mil)	Crevice Depth (mil)	Type[b]	Weld[b]	
Ni-Fe-Cr 800	W	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 800	S	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 800	W	403	6,780	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 800	S	403	6,780	<0.1	–	1	C	–	INCO (3)
Ni-Fe-Cr 800	W	751	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 800	S	751	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 800	W	1,064	5,300	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 800	S	1,064	5,300	<0.1	–	6	C	–	INCO (3)
Ni-Fe-Cr 800	W	197	2,340	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 800	S	197	2,340	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 800	W	402	2,370	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 800	W	402	2,370	0.0	–	–	NC	–	CEL (4)
Ni-Fe-Cr 800, welded, filler metal 82	W	402	2,370	<0.1	–	–	NC	WB; E (PR)	CEL (4)
Ni-Fe-Cr 800, welded, electrode 138	W	402	2,370	<0.1	–	–	NC	WB (E)[d]	CEL (4)
Ni-Fe-Cr 800	S	402	2,370	<0.1	–	–	ET	–	CEL (4)
Ni-Fe-Cr 800	S	402	2,370	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 800	W	181	5	<0.1	–	–	NC	–	CEL (4)
Ni-Fe-Cr 800	W	181	5	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 800	W	366	5	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 800	W	540	5	0.3	128	–	P (PR)	–	CEL (4)
Ni-Fe-Cr 800, welded, filler metal 82	W	540	5	0.4	128	–	P (PR)	T (WB&HAZ)	CEL (4)
Ni-Fe-Cr 800, welded, electrode 182	W	540	5	0.7	128	–	P (PR)	WB&HAZ (PR)	CEL (4)
Ni-Fe-Cr 804	W	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 804	S	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 804	W	403	6,780	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 804	S	403	6,780	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 804	W	751	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 804	S	751	5,640	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 804	W	1,064	5,300	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 804	S	1,064	5,300	<0.1	–	–	I-C	–	INCO (3)

Continued

Table 33. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mil)	Crevice Depth (mil)	Type[b]	Weld[b]	
Ni-Fe-Cr 804	W	197	2,340	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 804	S	197	2,340	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 804	W	402	2,370	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 804	S	402	2,370	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 804	W	181	5	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 804	W	366	5	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 825	W	123	5,640	0.0	–	–	NC	–	CEL (4)
Ni-Fe-Cr 825	W	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 825	W	123	5,640	0.1	–	–	NC; I-C	–	MEL (5)
Ni-Fe-Cr 825	S	123	5,640	<0.1	–	–	NC	–	CEL (4)
Ni-Fe-Cr 825	S	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 825	W	189	5,900	< 0.1	–	–	NC	–	CEL (4)
Ni-Fe-Cr 825	S	189	5,900	<0.1	–	–	NC	–	CEL (4)
Ni-Fe-Cr 825, longitudinal butt weld, electrode 135	W	189	5,900	<0.1	–	–	NC	WB (I-P)	CEL (4)
Ni-Fe-Cr 825, longitudinal butt weld, electrode 135	S	189	5,900	<0.1	–	–	NC	NC	CEL (4)
Ni-Fe-Cr 825, 3-in. circular weld, electrode 135	W	189	5,900	0.0	–	–	NC	NC	CEL (4)
Ni-Fe-Cr 825, 3-in. circular weld, electrode 135	S	189	5,900	<0.1	–	–	NC	NC	CEL (4)
Ni-Fe-Cr 825	W	403	6,780	0.0	–	–	NC	–	CEL (4)
Ni-Fe-Cr 825	W	403	6,780	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 825	S	403	6,780	0.0	–	–	NC	–	CEL (4)
Ni-Fe-Cr 825	S	403	6,780	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 825	W	751	5,640	<0.1	–	22	C	–	CEL (4)
Ni-Fe-Cr 825	W	751	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 825	W	751	5,640	0.4	1	63	C (PR); P	–	MEL (5)
Ni-Fe-Cr 825	S	751	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 825	W	1,064	5,300	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 825	S	1,064	5,300	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 825	W	197	2,340	0.0	–	–	NC	–	CEL (4)
Ni-Fe-Cr 825	W	197	2,340	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 825	S	197	2,340	<0.1	–	8	C	–	CEL (4)

Continued

Table 33. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mil)	Crevice Depth (mil)	Type[b]	Weld[b]	
Ni-Fe-Cr 825	S	197	2,340	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 825	W	402	2,370	<0.1	–	15	C; ET	–	CEL (4)
Ni-Fe-Cr 825	W	402	2,370	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 825, welded, filler metal 65	W	402	2,370	<0.1	–	–	NC	NC	CEL (4)
Ni-Fe-Cr 825, welded, electrode 135	W	402	2,370	<0.1	–	–	NC	WB[f]	CEL (4)
Ni-Fe-Cr 825	S	402	2,370	<0.1	–	8	C	–	CEL (4)
Ni-Fe-Cr 825	S	402	2,370	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 825	W	181	5	<0.1	44[g]	33	C; P	–	CEL (4)
Ni-Fe-Cr 825	W	181	5	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 825, welded, filler metal 65	W	181	5	<0.1	–	–	NC	NC	CEL (4)
Ni-Fe-Cr 825, welded, electrode 135	W	181	5	<0.1	–	–	NC	NC	CEL (4)
Ni-Fe-Cr 825	W	366	5	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 825	W	386[b]	5	<0.1	2	57	C; P	–	MEL (5)
Ni-Fe-Cr 825	W	398	5	<0.1	–	–	NC	–	CEL (4)
Ni-Fe-Cr 825	W	540	5	<0.1	43	24	C; P	–	CEL (4)
Ni-Fe-Cr 825, welded, filler metal 65	W	540	5	<0.1	4	–	P	I-P (WB&HAZ)	CEL (4)
Ni-Fe-Cr 825, welded, electrode 135	W	540	5	<0.1	6	–	I-C; P	CR (HAZ)	CEL (4)
Ni-Fe-Cr 825	W	588	5	<0.1	18	–	P	–	CEL (4)
Ni-Fe-Cr 825	W	608	5	<0.1	54	–	P	–	CEL (4)
Ni-Fe-Cr 825S[i]	W	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 825S	S	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 825S	W	403	6,780	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 825S	S	403	6,780	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 825S	W	751	5,640	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 825S	S	751	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 825S	W	1,064	5,300	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 825S	S	1,064	5,300	<0.1	–	4	C	–	INCO (3)
Ni-Fe-Cr 825S	W	197	2,340	<0.1	–	–	I-C; I-P	–	INCO (3)

Continued

Table 33. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mil)	Crevice Depth (mil)	Type[b]	Weld[b]	
Ni-Fe-Cr 825S	S	197	2,340	<0.1	–	–	I-C; I-P	–	INCO (3)
Ni-Fe-Cr 825S	W	402	2,370	<0.1	–	–	I-C; I-P	–	INCO (3)
Ni-Fe-Cr 825S	S	402	2,370	<0.1	–	–	I-C; I-P	–	INCO (3)
Ni-Fe-Cr 825S	W	181	5	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 825S	W	366	5	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 825Cb	W	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 825Cb	S	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 825Cb	W	403	6,780	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 825Cb	S	403	6,780	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 825Cb	W	751	5,640	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 825Cb	S	751	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 825Cb	W	1,064	5,300	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 825Cb	S	1,064	5,300	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 825Cb	W	197	2,340	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 825Cb	S	197	2,340	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 825Cb	W	402	2,370	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 825Cb	S	402	2,370	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 825Cb	W	181	5	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 825Cb	W	366	5	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 901	W	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 901	S	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 901	W	403	6,780	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 901	S	403	6,780	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 901	W	751	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 901	S	751	5,640	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 901	W	1,064	5,300	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 901	S	1,064	5,300	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 901	W	197	2,340	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 901	S	197	2,340	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 901	W	402	2,370	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 901	S	402	2,370	<0.1	–	–	I-C	–	INCO (3)
Ni-Fe-Cr 901	W	181	5	<0.1	–	–	NC	–	INCO (3)
Ni-Fe-Cr 901	W	366	5	<0.1	–	–	I-C	–	INCO (3)

Continued

Table 33. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mil)	Crevice Depth (mil)	Type[b]	Weld[b]	
Ni-Fe-Cr 902	W	402	2,370	1.4	–	35	C; I-P	–	CEL (4)
Ni-Fe-Cr 902	S	402	2,370	1.0	–	20	C; I-P	–	CEL (4)
Ni-Fe-Cr 902	W	181	5	2.2	–	26	C	–	CEL (4)
Ni-Fe-Cr 902	W	364	5	2.5	–	41	C	–	CEL (4)
Ni-Fe-Cr 902	W	723	5	1.7	–	40	C	–	CEL (4)
Ni-Fe-Cr 902	W	763	5	1.5	73	125	C (PR); P	–	CEL (4)
Ni-Cr-Mo 625	W	189	5,900	0.0	–	–	NC	–	CEL (4)
Ni-Cr-Mo 625	S	189	5,900	0.0	–	–	NC	–	CEL (4)
Ni-Cr-Mo 625, longitudinal butt weld, electrode 625	W	189	5,900	0.0	–	–	NC	NC	CEL (4)
Ni-Cr-Mo 625, longitudinal butt weld, electrode 625	S	189	5,900	0.0	–	–	NC	NC	CEL (4)
Ni-Cr-Mo 625, 3-in. circular weld, electrode 625	W	189	5,900	0.0	–	–	NC	NC	CEL (4)
Ni-Cr-Mo 625, 3-in. circular weld, electrode 625	S	189	5,900	0.0	–	–	NC	NC	CEL (4)
Ni-Cr-Mo 625	W	402	2,370	<0.1	–	–	NC	–	CEL (4)
Ni-Cr-Mo 625	W	402	2,370	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Mo 625	S	402	2,370	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Mo 625	W	181	5	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Mo 625	W	366	5	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Mo 625	W	398	5	0.0	–	–	NC	–	CEL (4)
Ni-Cr-Mo 625, welded, electrode 625	W	398	5	0.0	–	–	NC	NC	CEL (4)
Ni-Cr-Mo 625	W	540	5	0.0	–	–	NC	–	CEL (4)
Ni-Cr-Mo 625, welded, filler metal 625	W	540	5	0.0		–	NC	NC	CEL (4)
Ni-Cr-Mo 625, welded, electrode 625	W	540	5	0.0	–	–	NC	NC	CEL (4)
Ni-Cr-Mo 625	W	588	5	0.0	–	–	NC	–	CEL (4)
Ni-Cr-Mo 625, welded, electrode 625	W	588	5	0.0	–	–	NC	NC	CEL (4)
Ni-Mo-Cr C	W	123	5,640	<0.1	–	–	NC	–	CEL (4)
Ni-Mo-Cr C	W	123	5,640	<0.1	–	–	NC	–	INCO (3)

Continued

Table 33. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mil)	Crevice Depth (mil)	Type[b]	Weld[b]	
Ni-Mo-Cr C	W	123	5,640	<0.1	–	–	NC	–	MEL (5)
Ni-Mo-Cr C	S	123	5,640	<0.1	–	–	NC	–	CEL (4)
Ni-Mo-Cr C	S	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr C	W	403	6,780	0.0	–	–	NC	–	CEL (4)
Ni-Mo-Cr C	W	403	6,780	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr C	S	403	6,780	0.0	–	–	NC	–	CEL (4)
Ni-Mo-Cr C	S	403	6,780	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr C	W	751	5,640	0.0	–	–	NC	–	CEL (4)
Ni-Mo-Cr C	W	751	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr C	W	751	5,640	<0.1	–	–	NC	–	MEL (5)
Ni-Mo-Cr C	S	751	5,640	0.0	–	–	NC	–	CEL (4)
Ni-Mo-Cr C	S	751	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr C	W	1,064	5,300	0.0	–	–	NC	–	CEL (4)
Ni-Mo-Cr C	W	1,064	5,300	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr C	S	1,064	5,300	0.0	–	–	NC	–	CEL (4)
Ni-Mo-Cr C	S	1,064	5,300	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr C	W	197	2,340	0.0	–	–	NC	–	CEL (4)
Ni-Mo-Cr C	W	197	2,340	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr C	S	197	2,340	0.0	–	–	NC	–	CEL (4)
Ni-Mo-Cr C	S	197	2,340	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr C	W	402	2,370	0.0	–	–	NC	–	CEL (4)
Ni-Mo-Cr C	W	402	2,370	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr C	S	402	2,370	0.0	–	–	NC	–	CEL (4)
Ni-Mo-Cr C	S	402	2,370	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr C	W	181	5	<0.1	–	–	NC	–	CEL (4)
Ni-Mo-Cr C	W	181	5	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr C	W	366	5	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr C	W	398	5	<0.1	–	–	NC	–	CEL (4)
Ni-Mo-Cr C	W	608	5	0.0	–	–	NC	–	CEL (4)
Ni-Mo-Cr 3	W	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr 3	S	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr 3	W	403	6,780	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr 3	S	403	6,780	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr 3	W	751	5,640	<0.1	–	–	NC	–	INCO (3)

Continued

Table 33. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mil)	Crevice Depth (mil)	Type[b]	Weld[b]	
Ni-Mo-Cr 3	S	751	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr 3	W	1,064	5,300	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr 3	S	1,064	5,300	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr 3	W	197	2,340	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr 3	S	197	2,340	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr 3	W	402	2,370	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr 3	S	402	2,370	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr 3	W	181	5	<0.1	–	–	NC	–	INCO (3)
Ni-Mo-Cr 3	W	366	5	<0.1	–	–	NC	–	INCO (3)
Ni-Co-Cr 700	W	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Co-Cr 700	S	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Co-Cr 700	W	403	6,780	<0.1	–	–	NC	–	INCO (3)
Ni-Co-Cr 700	S	403	6,780	<0.1	–	–	NC	–	INCO (3)
Ni-Co-Cr 700	W	751	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Co-Cr 700	S	751	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Co-Cr 700	W	1,064	5,300	<0.1	–	–	NC	–	INCO (3)
Ni-Co-Cr 700	S	1,064	5,300	<0.1	–	–	I-C	–	INCO (3)
Ni-Co-Cr 700	W	197	2,340	<0.1	–	–	NC	–	INCO (3)
Ni-Co-Cr 700	S	197	2,340	<0.1	–	–	NC	–	INCO (3)
Ni-Co-Cr 700	W	402	2,370	<0.1	–	–	I-C	–	INCO (3)
Ni-Co-Cr 700	S	402	2,370	<0.1	–	–	I-C	–	INCO (3)
Ni-Co-Cr 700	W	181	5	<0.1	–	–	NC	–	INCO (3)
Ni-Co-Cr 700	W	366	5	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Co 41	W	1,064	5,300	0.0	–	–	NC	–	CEL (4)
Ni-Mo-Fe B	W	123	5,640	2.3	–	–	U	–	INCO (3)
Ni-Mo-Fe B	S	123	5,640	2.2	–	–	U	–	INCO (3)
Ni-Mo-Fe B	W	403	6,780	4.0	–	–	U	–	INCO (3)
Ni-Mo-Fe B	S	403	6,780	0.6	–	–	U[j]	–	INCO (3)
Ni-Mo-Fe B	W	751	5,640	2.9	–	–	G	–	INCO (3)
Ni-Mo-Fe B	S	751	5,640	1.8	–	–	G	–	INCO (3)
Ni-Mo-Fe B	W	1,064	5,300	1.5	–	–	G	–	INCO (3)
Ni-Mo-Fe B	S	1,064	5,300	0.8	–	–	NU	–	INCO (3)
Ni-Mo-Fe B	W	197	2,340	<0.1	–	–	NU-ET	–	INCO (3)

Continued

Table 33. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mil)	Crevice Depth (mil)	Type[b]	Weld[b]	
Ni-Mo-Fe B	S	197	2,340	<0.1	–	–	I-C; I-P	–	INCO (3)
Ni-Mo-Fe B	W	402	2,370	1.2	–	–	G	–	INCO (3)
Ni-Mo-Fe B	S	402	2,370	0.2	–	–	U	–	INCO (3)
Ni-Mo-Fe B	W	181	5	7.9	–	–	G	–	INCO (3)
Ni-Mo-Fe B	W	366	5	6.4	–	–	G	–	INCO (3)
Ni-Mo-Fe 2	W	123	5,640	1.2	–	–	G	–	INCO (3)
Ni-Mo-Fe 2	S	123	5,640	1.1	–	–	G	–	INCO (3)
Ni-Mo-Fe 2	W	403	6,780	2.2	–	–	G	–	INCO (3)
Ni-Mo-Fe 2	S	403	6,780	0.3	–	–	G	–	INCO (3)
Ni-Mo-Fe 2	W	751	5,640	6.8	–	–	G	–	INCO (3)
Ni-Mo-Fe 2	S	751	5,640	1.6	–	–	G	–	INCO (3)
Ni-Mo-Fe 2	W	1,064	5,300	3.2	–	–	G	–	INCO (3)
Ni-Mo-Fe 2	S	1,064	5,300	1.8	–	–	G	–	INCO (3)
Ni-Mo-Fe 2	W	197	2,340	1.0	–	–	G	–	INCO (3)
Ni-Mo-Fe 2	S	197	2,340	0.2	–	–	G	–	INCO (3)
Ni-Mo-Fe 2	W	402	2,370	1.6	–	–	G	–	INCO (3)
Ni-Mo-Fe 2	S	402	2,370	0.3	–	–	ET	–	INCO (3)
Ni-Mo-Fe 2	W	181	5	4.7	5	–	P	–	INCO (3)
Ni-Mo-Fe 2	W	366	5	4.7	12	–	P	–	INCO (3)
Ni-Cr-Fe-Mo F	W	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo F	S	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo F	W	403	6,780	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo F	S	403	6,780	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo F	W	751	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo F	S	751	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo F	W	1,064	5,300	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo F	S	1,064	5,300	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo F	W	197	2,340	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo F	S	197	2,340	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo F	W	402	2,370	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo F	S	402	2,370	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo F	W	181	5	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo F	W	366	5	<0.1	–	–	NC	–	INCO (3)

Continued

Table 33. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mil)	Crevice Depth (mil)	Type[b]	Weld[b]	
Ni-Cr-Fe-Mo G	W	402	2,370	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo G	S	402	2,370	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo G	W	181	5	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo G	W	366	5	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo X	W	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo X	S	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo X	W	403	6,780	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo X	S	403	6,780	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo X	W	751	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo X	S	751	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo X	W	1,064	5,300	<0.1	–	–	SL-ET	–	INCO (3)
Ni-Cr-Fe-Mo X	S	1,064	5,300	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo X	W	197	2,340	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo X	S	197	2,340	<0.1	–	–	I-C	–	INCO (3)
Ni-Cr-Fe-Mo X	W	402	2,370	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo X	S	402	2,370	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo X	W	181	5	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe-Mo X	W	366	5	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe 88	W	123	5,640	0.1	–	4	C	–	INCO (3)
Ni-Cr-Fe 88	S	123	5,640	0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe 88	W	403	6,780	<0.1	–	5	C	–	INCO (3)
Ni-Cr-Fe 88	S	403	6,780	<0.1	–	–	NC	–	INCO (3)
Ni-Cr-Fe 88	W	751	5,640	<0.1	–	–	I-C	–	INCO (3)
Ni-Cr-Fe 88	S	751	5,640	1.3	180	–	P (PR)[k]	–	INCO (3)
Ni-Cr-Fe 88	W	1,064	5,300	<0.1	–	67	C	–	INCO (3)
Ni-Cr-Fe 88	S	1,064	5,300	<0.1	–	5	C	–	INCO (3)
Ni-Cr-Fe 88	W	197	2,340	0.3	-	17	C; P	–	INCO (3)
Ni-Cr-Fe 88	S	197	2,340	<0.1	–	–	I-C	–	INCO (3)
Ni-Cr-Fe 88	W	402	2,370	0.4	–	52	C; P	–	INCO (3)
Ni-Cr-Fe 88	S	402	2,370	<0.1	–	–	I-C	–	INCO (3)
Ni-Cr-Fe 88	W	181	5	1.1	108	17	C; P	–	INCO (3)
Ni-Cr-Fe 88	W	366	5	1.0	150	–	P	–	INCO (3)

Continued

Table 33. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mil)	Crevice Depth (mil)	Type[b]	Weld[b]	
Ni-Sn-Zn 23	W	123	5,640	2.6	–	25	C	–	INCO (3)
Ni-Sn-Zn 23	S	123	5,640	1.8	–	14	C	–	INCO (3)
Ni-Sn-Zn 23	W	403	6,780	8.4	–	36	C; P	–	INCO (3)
Ni-Sn-Zn 23	S	403	6,780	<0.1	–	–	NC	–	INCO (3)
Ni-Sn-Zn 23	W	751	5,640	3.5	–	56	C; P	–	INCO (3)
Ni-Sn-Zn 23	S	751	5,640	2.1	–	52	C; P	–	INCO (3)
Ni-Sn-Zn 23	W	1,064	5,300	1.7	–	50	C; P	–	INCO (3)
Ni-Sn-Zn 23	S	1,064	5,300	1.0	35	–	P	–	INCO (3)
Ni-Sn-Zn 23	W	197	2,340	0.5	–	15	C	–	INCO (3)
Ni-Sn-Zn 23	S	197	2,340	<0.1	–	–	I-C	–	INCO (3)
Ni-Sn-Zn 23	W	402	2,370	0.9	–	29	C	–	INCO (3)
Ni-Sn-Zn 23	S	402	2,370	0.1	–	–	I-C	–	INCO (3)
Ni-Sn-Zn 23	W	181	5	3.7	37	27	C; P	–	INCO (3)
Ni-Sn-Zn 23	W	366	5	4.5	37	37	C; P	–	INCO (3)
Ni-Be	W	402	2,370	1.1	17	–	ET; P[l]	–	CEL (4)
Ni-Be	S	402	2,370	0.7	8	–	ET; P[l]	–	CEL (4)
Ni-Be	W	364	5	5.4	152	–	ET; P[l]	–	CEL (4)
Ni-Be	W	763	5	4.9	345	–	CR (43); P[l]	–	CEL (4)
Ni-Cr, 65-35	W	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Cr, 65-35	S	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Cr, 65-35	W	403	6,780	<0.1	–	35	C (PR)	–	INCO (3)
Ni-Cr, 65-35	S	403	6,780	<0.1	–	–	I-C	–	INCO (3)
Ni-Cr, 65-35	W	751	5,640	<0.1	–	20	C	–	INCO (3)
Ni-Cr, 65-35	S	751	5,640	<0.1	–	–	I-C	–	INCO (3)
Ni-Cr, 65-35	W	1,064	5,300	<0.1	–	5	C	–	INCO (3)
Ni-Cr, 65-35	S	1,064	5,300	0.1	–	50	C (PR)	–	INCO (3)
Ni-Cr, 65-35	W	197	2,340	0.3	–	24	C	–	INCO (3)
Ni-Cr, 65-35	S	197	2,340	<0.1	–	–	I-C	–	INCO (3)
Ni-Cr, 65-35	W	402	2,370	0.1	–	6	C	–	INCO (3)
Ni-Cr, 65-35	S	402	2,370	<0.1	–	–	I-C	–	INCO (3)
Ni-Cr, 65-35	W	181	5	2.4	50	50	C (PR); P (PR)	–	INCO (3)
Ni-Cr, 65-35	W	366	5	1.9	30	30	C (PR); P (PR)	–	INCO (3)

Continued

Table 33. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mil)	Crevice Depth (mil)	Type[b]	Weld[b]	
Ni-Cr, 75	W	123	5,640	<0.1	–	–	I-C	–	INCO (3)
Ni-Cr, 75	S	123	5,640	<0.1	–	–	NC	–	INCO (3)
Ni-Cr, 75	W	403	6,780	0.4	–	40	C (PR)	–	INCO (3)
Ni-Cr, 75	S	403	6,780	<0.1	–	–	I-C	–	INCO (3)
Ni-Cr, 75	W	751	5,640	0.5	–	40	C (PR); P	–	INCO (3)
Ni-Cr, 75	S	751	5,640	<0.1	–	2	C	–	INCO (3)
Ni-Cr, 75	W	1,064	5,300	<0.1	–	–	I-C	–	INCO (3)
Ni-Cr, 75	S	1,064	5,300	<0.1	–	12	C	–	INCO (3)
Ni-Cr, 75	W	197	2,340	0.3	–	40	C (PR)	–	INCO (3)
Ni-Cr, 75	S	197	2,340	<0.1	–	5	C	–	INCO (3)
Ni-Cr, 75	W	402	2,370	0.4	–	40	C (PR)	–	INCO (3)
Ni-Cr, 75	S	402	2,370	<0.1	–	–	I-C	–	INCO (3)
Ni-Cr, 75	W	181	5	1.5	50	50	C (PR); P (PR)	–	INCO (3)
Ni-Cr, 75	W	366	5	1.2	50	50	C (PR); P (PR)	–	INCO (3)
Ni-Cr, 80-20	W	123	5,640	<0.1	–	2	C	–	INCO (3)
Ni-Cr, 80-20	S	123	5,640	<0.1	–	–	I-C	–	INCO (3)
Ni-Cr, 80-20	W	403	6,780	0.2	–	11	C	–	INCO (3)
Ni-Cr, 80-20	S	403	6,780	<0.1	–	–	I-C	–	INCO (3)
Ni-Cr, 80-20	W	751	5,640	0.4	–	32	C (PR)	–	INCO (3)
Ni-Cr, 80-20	S	751	5,640	<0.1	–	–	I-C	–	INCO (3)
Ni-Cr, 80-20	W	1,064	5,300	<0.1	–	5	C	–	INCO (3)
Ni-Cr, 80-20	S	1,064	5,300	0.1	–	50	C (PR)	–	INCO (3)
Ni-Cr, 80-20	W	197	2,340	0.2	–	32	C (PR)	–	INCO (3)
Ni-Cr, 80-20	S	197	2,340	<0.1	–	–	I-C; E	–	INCO (3)
Ni-Cr, 80-20	W	402	2,370	0.2	–	18	C; P	–	INCO (3)
Ni-Cr, 80-20	S	402	2,370	<0.1	–	–	I-C	–	INCO (3)
Ni-Cr, 80-20	W	181	5	2.6	50	50	C (PR); P (PR)	–	INCO (3)
Ni-Cr, 80-20	W	366	5	1.6	30	30	C (PR); P (PR)	–	INCO (3)
Ni-Si D	W	123	5,640	1.3	–	12	C	–	INCO (3)
Ni-Si D	S	123	5,640	1.4	–	10	C	–	INCO (3)
Ni-Si D	W	403	6,780	2.4	–	5	C; P	–	INCO (3)
Ni-Si D	S	403	6,780	1.4	–	14	C	–	INCO (3)
Ni-Si D	W	751	5,640	1.7	–	29	C	–	INCO (3)
Ni-Si D	S	751	5,640	1.5	–	6	C; P	–	INCO (3)

Continued

Table 33. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mil)	Crevice Depth (mil)	Type[b]	Weld[b]	
Ni-Si D	W	1,064	5,300	1.6	38	42	C; P	–	INCO (3)
Ni-Si D	S	1,064	5,300	1.1	20	25	C; P	–	INCO (3)
Ni-Si D	W	197	2,340	0.2	–	–	I-C	–	INCO (3)
Ni-Si D	S	197	2,340	<0.1	–	–	I-C	–	INCO (3)
Ni-Si D	W	402	2,370	0.5	–	14	C	–	INCO (3)
Ni-Si D	S	402	2,370	0.2	–	–	ET	–	INCO (3)
Ni-Si D	W	181	5	2.5	19	25	C; P	–	INCO (3)
Ni-Si D	W	366	5	1.9	37	33	C; P	–	INCO (3)

[a]W = Totally exposed in seawater on sides of structure; S = Exposed in base of structure so that the lower portions of the specimen were embedded in the bottom sediments.

[b]Symbols for types of corrosion:

C = Crevice		NU = Nonuniform	
.CR = Cratering		P = Pitting	
E = Edge		PR = Perforation	
ET = Etched		SL = Slight	
G = General		T = Tunneling	
HAZ = Heat affected zone		U = Uniform	
I = Incipient		WB = Weld bead	
NC = No visible corrosion			

Numbers indicate maximum depth in mils.

[c]Numbers refer to references at end of report.

[d]Line corrosion at edge of weld bead.

[e]Only two deep pits.

[f]One end corroded.

[g]Under barnacles.

[h]Francis L. LaQue Corrosion Laboratory, INCO, Wrightsville Beach, N.C.

[i]Sensitized by heating 1 hour at 1,200°F and then air cooling.

[j]Groove at mud line.

[k]Only one pit.

[l]Pitting only on ends of bars.

Table 34. Changes in Mechanical Properties of Nickel Alloys Due to Corrosion

Alloy	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[a]
			Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
Ni-Cr-Fe 600	197	2,340	111	0	51	+7	51	-30	NADC (7)
Ni-Cr-Fe 600	403	2,370	111	-16	51	-14	51	-15	NADC (7)
Ni-Fe-Cr 825	123	5,640	108	0	52	+4	38	0	CEL (4)
Ni-Fe-Cr 825	403	6,780	108	0	52	+3	38	-4	CEL (4)
Ni-Fe-Cr 825	751	5,640	108	+2	52	+5	38	-3	CEL (4)
Ni-Fe-Cr 825	197	2,340	108	0	52	+4	38	-6	CEL (4)
Ni-Fe-Cr 825	402	2,370	108	+1	52	+4	38	-3	CEL (4)
Ni-Fe-Cr 825	181	5	108	+1	52	-2	38	-7	CEL (4)
Ni-Fe-Cr 902	402	2,370	99	-2	40	-8	43	-49	CEL (4)
Ni-Fe-Cr 902	181	5	99	-1	40	+6	43	-50	CEL (4)
Ni-Mo-Cr C	123	5,640	121	+3	60	+5	43	-1	CEL (4)
Ni-Mo-Cr C	403	6,780	121	+5	60	+1	43	+15	CEL (4)
Ni-Mo-Cr C	751	5,640	121	+4	60	0	43	+15	CEL (4)
Ni-Mo-Cr C	1,064	5,300	121	+3	60	-7	43	+15	CEL (4)
Ni-Mo-Cr C	197	2,340	121	+3	60	-1	43	+18	CEL (4)
Ni-Mo-Cr C	402	2,370	121	+3	60	+3	43	+12	CEL (4)
Ni-Mo-Cr C	181	5	121	+3	60	-1	43	+15	CEL (4)
Ni-Be, 1/2 H[b]	197	2,340	134	-2	124	0	12	0	NADC (7)
Ni-Be, 1/2 H	402	2,370	134	-3	124	-2	12	-14	NADC (7)
Ni-Be, 1/2 HT[c]	197	2,340	248	-2	200	0	9	-33	NADC (7)
Ni-Be, 1/2 HT	402	2,370	248	-5	200	–	9	-60	NADC (7)

[a]Numbers refer to references at end of report.

[b]Age hardened.

[c]Age hardened and cold worked.

Table 35. Stress Corrosion of Nickel Alloys

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed	Source[a]
Ni-200	13	50	402	2,370	3	0	CEL (4)
Ni-200	19	75	402	2,370	3	0	CEL (4)
Ni-Cu 400	14	50	402	2,370	3	0	CEL (4)
Ni-Cu 400	22	75	402	2,370	3	0	CEL (4)
Ni-Cu 400	12	30	403	6,780	3	0	NADC (7)
Ni-Cu 400	31	75	403	6,780	3	0	NADC (7)
Ni-Cu 400	12	30	197	2,340	3	0	NADC (7)
Ni-Cu 400	31	75	197	2,340	3	0	NADC (7)
Ni-Cu 400	12	30	402	2,370	3	0	NADC (7)
Ni-Cu 400	31	75	402	2,370	3	0	NADC (7)
Ni-Cu K-500	120	—	402	2,370	3	0	Shell (9)
Ni-Cr-Fe 600	15	30	403	6,780	3	0	NADC (7)
Ni-Cr-Fe 600	38	75	403	6,780	3	0	NADC (7)
Ni-Cr-Fe 600	15	30	197	2,340	3	0	NADC (7)
Ni-Cr-Fe 600	38	75	197	2,340	3	0	NADC (7)
Ni-Cr-Fe 600	15	30	402	2,370	3	0	NADC (7)
Ni-Cr-Fe 600	38	75	402	2,370	3	0	NADC (7)
Ni-Cr-Fe X-750	120	—	402	2,370	3	0	Shell (9)
Ni-Mo-Cr C	21	35	123	5,640	3	0	CEL (4)
Ni-Mo-Cr C	30	50	123	5,640	3	0	CEL (4)
Ni-Mo-Cr C	45	75	123	5,640	3	0	CEL (4)
Ni-Mo-Cr C	21	35	403	6,780	3	0	CEL (4)
Ni-Mo-Cr C	30	50	403	6,780	3	0	CEL (4)
Ni-Mo-Cr C	45	75	403	6,780	3	0	CEL (4)
Ni-Mo-Cr C	21	35	751	5,640	3	0	CEL (4)
Ni-Mo-Cr C	30	50	751	5,640	3	0	CEL (4)
Ni-Mo-Cr C	45	75	751	5,640	3	0	CEL (4)
Ni-Mo-Cr C	21	35	197	2,340	3	0	CEL (4)
Ni-Mo-Cr C	30	50	197	2,340	3	0	CEL (4)
Ni-Mo-Cr C	45	75	197	2,340	3	0	CEL (4)
Ni-Mo-Cr C	30	50	402	2,370	3	0	CEL (4)
Ni-Mo-Cr C	45	75	402	2,370	3	0	CEL (4)
Ni-Fe-Cr 825	26	50	402	2,370	3	0	CEL (4)
Ni-Fe-Cr 825	39	75	402	2,370	3	0	CEL (4)
Ni-Be, 1/2 H	37	30	403	6,780	3	0	NADC (7)
Ni-Be, 1/2 H	93	75	403	6,780	3	0	NADC (7)
Ni-Be, 1/2 H	37	30	197	2,340	3	0	NADC (7)

Continued

Table 35. Continued.

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed	Source[a]
Ni-Be, 1/2 H	93	75	197	2,340	3	0	NADC (7)
Ni-Be, 1/2 H	37	30	402	2,370	3	0	NADC (7)
Ni-Be, 1/2 H	93	75	402	2,370	3	0	NADC (7)
Ni-Be, 1/2 HT	60	30	403	6,780	3	0	NADC (7)
Ni-Be, 1/2 HT	60	30	197	2,340[b]	3	0	NADC (7)
Ni-Be, 1/2 HT	60	30	402	2,370	3	0	NADC (7)

[a]Numbers refer to references at end of report.

[b]Severe corrosion at sheared edges indicating possible susceptibility to stress corrosion cracking.

SECTION 5

STAINLESS STEELS

The corrosion resistance of stainless steels is attributed to a very thin, stable oxide film on the surface of the alloy which results from the alloying of carbon steels with chromium. Chromium, being a passive metal (corrosion resistant), imparts its passivity to steel when alloyed with it in amounts of 12% or greater. These iron-chromium alloys are very corrosion-resistant in oxidizing environments because the passive film is maintained in most environments when a sufficient amount of oxidizing agent or oxygen is present to repair any breaks in the protective film.

The corrosion resistance of stainless steels is further enhanced by the addition of nickel to the iron-chromium alloys. This group of alloys is popularly known as the 18-8 (18% chromium – 8% nickel) stainless steels.

In general, oxidizing conditions favor passivity (corrosion resistance), while reducing conditions destroy it. Chloride ions are particularly agressive in destroying this passivity.

Stainless steels usually corrode by pitting and crevice corrosion in seawater. Pits begin by breakdown of the passive film at weak spots or at nonhomogeneities. The breakdown is followed by the formation of an electrolytic cell, the anode of which is a minute area of active metal and the cathode of which is a considerable area of passive metal. The large potential difference characteristic of this "passive-active" cell accounts for considerable flow of current with attendant rapid corrosion (pitting) at the small anode.

Pitting is most likely to occur in the presence of chloride ions (for example, seawater), combined with such depolarizers as oxygen or oxidizing salts. An oxidizing environment is usually necessary for preservation of passivity with accompanying high corrosion resistance; but, unfortunately, it is also a favorable condition for pitting. The oxidizer can often act as a depolarizer for passive-active cells that were established by breakdown of passivity at a specific point or area. The chloride ion in particular can accomplish this breakdown.

Stainless steels can and do pit in aerated seawater (near neutral chloride solution). Pitting is less pronounced in rapidly moving seawater (aerated solution) as compared with partially aerated, stagnant seawater. The flow of seawater carries away corrosion products which would otherwise accumulate at crevices or cracks. It also insures uniform passivity through free access of dissolved oxygen.

As discussed above, stainless steels generally corrode in seawater by pitting and crevice corrosion; therefore, as much as 90 to 95% of the exposed surface can be uncorroded. With such low percentages of the total exposed area affected, corrosion calculated from loss in weight as mils penetration per year (mpy) can give a very misleading picture. The mpy implies a uniform decrease in thickness, which, for stainless steels, is not the case.

A manifestation of pitting corrosion, whose presence and extent is often overlooked, is tunnel corrosion. Tunnel corrosion is also classified by some as edge, honeycomb, or underfilm corrosion. Tunnel corrosion is insidious because of its nature and because many times it is not apparent from the outside surfaces of the object. It starts as a pit on the surface or on an edge and propagates laterally through the material, many times leaving thin films of uncorroded metal on the exposed surfaces.

Another manifestation of localized attack in stainless steels is oxygen concentration cell corrosion in crevices (usually known as crevice corrosion). This type of corrosion occurs underneath deposits of any kind on the metal surface, underneath barnacles, and at the faying surfaces of a joint. The area of stainless steel that is shielded from the surrounding solution becomes deficient in oxygen, thus creating a difference in oxygen concentration between the shielded and unshielded areas. An electrolytic cell is created, with a difference of potential being generated between the high and low oxygen concentration areas (the low oxygen concentration area becomes the anode of the cell).

Low weight losses and corrosion rates accompany these manifestations of corrosion. Thus, the integrity of a stainless steel structure can be jeopardized if designed solely on the basis of corrosion rates calculated from weight losses rather than on the basis of measured depths of pits, lengths of tunnel corrosion, and depths of crevice corrosion. Pitting, tunneling, and crevice corrosion, can and do penetrate stainless steel rapidly, thus rendering it useless in short periods of time.

Therefore, corrosion rates expressed as mpy calculated from weight losses, maximum pit depths, maximum lengths of tunnel corrosion, maximum depths of crevice corrosion, and types of corrosion are tabulated to provide an overall picture of the corrosion of the stainless steels.

5.1. AISI 200 SERIES STAINLESS STEELS

The chemical compositions of the AISI 200 Series stainless steels are given in Table 36, their corrosion rates and types of corrosion in Table 37, their stress corrosion behavior in Table 38, and the effect of exposure on their mechanical properties in Table 39.

The AISI 200 Series stainless steels are 300 Series stainless steels modified by substituting manganese for about one-half of the nickel. This modification does not adversely affect the corrosion resistance of iron-chromium-nickel alloys in many environments.

5.1.1. Duration of Exposure

The AISI 201 and 202 alloys were attacked by crevice and pitting types of corrosion both at the surface and at depths in the seawater. There was a tendency for both alloys to be more severely corroded after longer periods of exposure both at the surface and at depth. The bottom sediments were about as corrosive as the seawater above them.

5.1.2. Effect of Depth

The corrosion of AISI 201 was approximately the same at the surface as at depth, while that of AISI 202 was less severe at depth than at the surface. However, it was concluded that depth had no definite influence on the corrosion of the AISI 200 Series stainless steels.

5.1.3. Effect of Concentration of Oxygen

The effect of changes in the concentration of oxygen in seawater on the corrosion of both AISI 201 and 202 stainless steels was nonuniform. In general, crevice and pitting corrosion were more rapid and severe at the surface than at depth, but there was no definite correlation between corrosion and oxygen concentration.

As is well known, oxygen can and does play a dual role in the corrosion of stainless steels in electrolytes (for example, seawater). An oxidizing environment (presence of oxygen or other oxidizers) is necessary for maintaining the passivity of stainless steels. However, this same oxidizing environment is necessary to initiate and maintain pitting in stainless steels. Oxygen often acts as the depolarizer for passive-active cells created by the breakdown of passivity at a specific point or area. The chloride ion (present in abundance in seawater) is singularly efficient in accomplishing this breakdown. Therefore, this dual role of oxygen can be used to explain the inconsistent and erratic corrosion behavior of stainless steels in seawater.

5.1.4. Stress Corrosion

AISI 201 stainless steel was exposed at the depths and for the times shown in Table 38 when stressed at values equivalent to 30 and 75% of its yield strength to determine its susceptibility to stress corrosion. AISI 201 stainless steel was not susceptible to stress corrosion under the above conditions of test.

5.1.5. Mechanical Properties

The effects of exposure on the mechanical properties of AISI 201 and 202 stainless steels are given in Table 39. The mechanical properties were not adversely affected.

5.2. AISI 300 SERIES STAINLESS STEELS

The chemical compositions of the AISI 300 Series stainless steels are given in Table 40, their corrosion rates and types of corrosion in Table 41, their stress corrosion behavior in Table 42, and the effect of exposure on their mechanical properties in Table 43.

The corrosion of the AISI 300 Series stainless steels was very erratic and unpredictable. They were attacked by crevice, pitting, and tunnel types of corrosion, in varying degrees of severity ranging from incipient to perforation of the thickness of the specimens and tunnels extending laterally for a distance of 11 inches (11,000 mils) through the specimen. Comparing the intensities of these types of localized corrosion with the corresponding corrosion rates indicates no definite correlation between them.

Two alloys, AISI 317 and 329, were attacked only by incipient crevice corrosion during exposures at all three depths (surface, 2,500, and 6,000 feet) in seawater for periods ranging from 366 days at the surface to 1,064 days at the 6,000-foot depth.

Sensitization (heating for 1 hour at 1,200°F and cooling in air) rendered AISI 304 and 316 stainless steels more susceptible to corrosion than their unsensitized counterparts.

5.2.1. Duration of Exposure

Examination of the data in Table 41 shows that there is no definite or consistent correlation between severity of corrosion or corrosion rates and duration of exposure. For example, at the 6,000-foot depth in seawater the intensities of pitting and tunnel corrosion were greater after 403 days than after 1,064 days of exposure, the intensity of crevice corrosion was greater after 1,064 days than after 403 days of exposure, and the maximum corrosion rate was greater after 1,064 days than after 403 days of exposure.

5.2.2. Effect of Depth

The data in Table 41 show, in general, that the intensities of crevice, pitting, and tunnel corrosion were either about the same or greater at the surface than at the depth. The corrosion rates are in agreement with this conclusion in that those of most of the alloys were greater at the surface than at depth. Based on these data and the above statements, it is concluded that depth in the ocean exerts no significant influence on the corrosion of AISI 300 Series stainless steels.

5.2.3. Effect of Concentration of Oxygen

There was no definite correlation between the intensities of pitting, tunnel, and crevice corrosion of the AISI 300 Series stainless steels and changes in the concentration of oxygen in seawater after 1 year of exposure. On the basis of corrosion rates for those alloys which had definite weight losses, the rates increased with increasing concentration of oxygen, but not uniformly.

These data indicate that the corrosion of the AISI 300 Series stainless steels is not proportional to changes in the concentration of oxygen in seawater. The dual role oxygen plays in the corrosion of stainless steels in seawater, as discussed previously, also applies here as an explanation for the erratic behavior of AISI 300 Series stainless steels.

5.2.4. Stress Corrosion

Some of the AISI 300 Series stainless steels were stressed at values ranging from 30 to 80% of their respective yield strengths. They were exposed in the seawater at depths of 2,500 and 6,000 feet for various periods of time to determine their susceptibility to stress corrosion cracking. These data are given in Table 42.

None of the steels were susceptible to stress corrosion under the conditions of these tests.

5.2.5. Mechanical Properties

The effects of exposure on the mechanical properties of some of the 300 Series stainless steels are given in Table 43.

In only two cases were the mechanical properties adversely affected: (1) After 1,064 days of exposure at the 6,000-foot depth, the tensile and yield strengths and the elongation of AISI 304L were reduced by about 30%. This is attributed to the perforation of the specimen by both crevice and pitting corrosion, and edge and tunnel corrosion. (2) After 402 days of exposure at the 2,500-foot depth, the tensile and yield strengths of welded, sensitized AISI 316 were reduced by 45%. These reductions are attributed to the effects of welding.

5.3. AISI 400 SERIES STAINLESS STEELS

The chamical compositions of the AISI 400 Series stainless steels are given in Table 44, their corrosion rates and type of corrosion in Table 45, their stress corrosion behavior in Table 46, and the effect of exposure on their mechanical properties in Table 47.

The AISI 400 Series stainless steels are those which nominally contain 11 to 27% chromium. The 400 Series stainless steels are further divided into ferritic and martensitic steels. The ferritic steels are nonhardenable by heat treatment; those in this category in this program were AISI 405, 430, and 446. The martensitic steels are hardenable by heat treatment, and the one in this category in this program was AISI 410.

The corrosion of the AISI 400 Series stainless steels was erratic and was characterized by the localized types of corrosion (crevice, pitting, and tunnel). The intensities of these types varied from none to complete perforation of the thickness of the specimens for the crevice and pitting types and tunnel corrosion extending laterally the entire 12-inch (12,000 mils) length of specimens. There was no correlation between the intensities of these types of localized corrosion and the corresponding corrosion rates calculated from weight losses. The frequencies and intensities of these types of corrosion were also greater for the AISI 400 Series stainless steels than for the AISI 300 Series stainless steels.

5.3.1. Duration of Exposure

The data in Table 45 show no correlation between either intensities of the localized types of corrosion or corrosion rates and duration of exposure. Neither one decreased or increased continuously with increasing duration of exposure.

5.3.2. Effect of Depth

Depth had no uniform or gradual effect on the corrosion rates of the AISI 400 Series stainless steels, although the rates were lower at depth than at the surface. However, these corrosion rates did not decrease with increasing depth, i.e., they were lower at the 2,500-foot depth than at the 6,000-foot depth for two of the four steels. The intensities of the localized types of corrosion were either the same or greater at the surface as at depth.

Depth had no definite influence on the corrosion of the AISI 400 Series stainless steels.

5.3.3. Effect of Concentration of Oxygen

In general, the corrosion rates of the AISI 400 Series stainless steels were higher at the highest concentration of oxygen (at the surface) than at the lower concentrations. However, the increases were not proportional to the increase in the oxygen concentration except for AISI 410 after 1 year of exposure. The intensities of the localized types of corrosion were not influenced by changes in the concentration of oxygen in the seawater.

In general, changes in the concentration of oxygen in seawater did not exert a major influence on the corrosion of the AISI 400 Series stainless steels.

5.3.4. Stress Corrosion

The AISI 400 Series stainless steels were stressed at values ranging from 30 to 75% of their respective yield strengths. They were exposed in seawater at the 2,500- and 6,000-foot depths for various periods of time to determine their susceptibilities to stress corrosion cracking. These data are given in Table 46.

None of the AISI 400 Series stainless steels were susceptible to stress corrosion under the conditions of these tests.

5.3.5. Mechanical Properties

The effects of exposure on the mechanical properties of the AISI 400 Series stainless steels are given in Table 47.

In only two cases were the mechanical properties seriously impaired: (1) After 403 days of exposure at the 6,000-foot depth, the tensile and yield strengths and the elongation of AISI 405 were seriously reduced. (2) After 751 days of exposure at the 6,000-foot depth, the tensile and yield strengths and the elongation of AISI 430 were completely destroyed.

In all other exposures and for the other steels there was no impairment of the mechanical properties.

5.3.6. Corrosion Products

The corrosion products taken from one of the corrosion tunnels in AISI Type 430 stainless steel were analyzed by X-ray diffraction, spectrographic analysis, quantitative chemical analysis, and infra-red spectrophotometry and were found to contain amorphous ferric oxide ($Fe_2O_3 \cdot XH_2O$), Fe, Cr, Mn, Si, trace of Ni, 1.41% chloride ion, 2.12% sulfate ion, and a significant amount of phosphate ion.

5.4. PRECIPITATION-HARDENING STAINLESS STEEL

The chemical compositions of the precipitation-hardening stainless steels are given in Table 48, their corrosion rates and types of corrosion in Table 49, their stress corrosion behavior in Tables 50 and 51, and the effect of exposure on their mechanical properties in Table 52.

The precipitation-hardening stainless steels differ from the conventional stainless steels (AISI Series 200, 300, and 400) in that they can be hardened to very high strength levels by heating the annealed steels to temperatures in the 900 to 1,200^{o}F range and then cooling in air.

The corrosion of the precipitation-hardening stainless steels was erratic and was of the crevice, pitting, and tunnel types of localized corrosion with some edge attack. There was no correlation between the intensities of these types of localized corrosion and the corresponding corrosion rates calculated from weight losses. The frequencies and intensities of these types of corrosion were greater for the precipitation-hardening stainless steels than for the AISI 300 Series stainless steels.

The 15-7AMV steels corroded at extremely rapid rates by crevice, pitting, tunnel, and edge corrosion. In many instances, large portions of the specimens had been lost due to corrosion; in other cases tunnel corrosion had extended laterally through the specimens for distances of 11 or 12 inches within a year of exposure. They were considerably more susceptible to corrosion than were the other precipitation-hardening stainless steels.

Alloy 17Cr-14Ni-Cu-Mo was nearly free of corrosion after exposure for 366 days at the surface, 402 days at 2,500 feet, and 1,064 days at 6,000 feet. There was one case of pitting to a depth of 3 mils after 181 days of exposure at the surface. There was incipient crevice corrosion at the surface and at depth except for pitting to a depth of 3 mils after 1,064 days of exposure in the bottom sediment at the 6,000-foot depth.

5.4.1. Duration of Exposure

The data in Table 49 show that there was no correlation between the intensities of the localized types of corrosion and duration of exposure. Also, there was no correlation between corrosion rates calculated from weight losses and duration of exposure except for the 15-7AMV steels for which the corrosion rates increased with increasing time of exposure.

5.4.2. Effect of Depth

In general, depth had no effect on the corrosion of the precipitation-hardening stainless steels.

5.4.3. Effect of Concentration of Oxygen

Changes in the concentration of oxygen in seawater exerted no definite or major influence on the corrosion behavior of the precipitation-hardening stainless steels.

5.4.4. Effect of Welding

A 3-inch-diameter circular, unrelieved weld was made in the center of the 6 x 12-inch specimens of some of the alloys to impose residual stresses in the specimens. Others had a 6-inch-long transverse, unrelieved butt weld across the center of the 6 x 12-inch specimens. These welds were to determine whether welding affected the corrosion behavior and stress corrosion susceptibilities of the alloys.

Welding did not affect the corrosion behavior of the precipitation-hardening stainless steels.

The effects of residual stresses imposed by welding will be discussed under 5.4.5.

5.4.5. Stress Corrosion

The precipitation-hardening stainless steels were stressed at values ranging from 35 to 85% of their respective yield strengths. They were exposed in seawater at the surface, 2,500-, and 6,000-foot depths for various periods of time to determine their susceptibilities to stress corrosion. Their data are given in Table 50. A 3-inch-diameter circular, unrelieved weld was made in the center of the 6 x 12-inch specimens of some alloys to impose residual stresses in them. Transverse, unrelieved butt welds were made in other specimens for the purpose of simulating stresses induced during construction or fabrication. These residual stresses were multiaxial rather than uniaxial as was the case with the specimens with calculated stresses. In addition, values of these residual stresses were indeterminable. These specimens were exposed in seawater under the same conditions as those above. Their data are given in Table 51.

Alloy AISI 630,H925 with a transverse butt weld did not fail by stress corrosion when stressed to 75% of its yield strength either at the surface or at depth. However, it did fail due to the unrelieved stresses imposed by the circular weld after 403 days of exposure at the 6,000-foot depth. The crack propagated across the weld bead.

Specimens of transverse, butt-welded AISI 631,TH1050 failed when stressed to 50% of its yield strength and exposed both at the surface and at depth. Specimens with circular welds also failed when exposed at the surface and at depth. At the surface the cracks extended radially from a point inside the circle to the circular weld bead. At depth the crack extended across and around the outside edge of the weld bead.

Specimens of transverse, butt-welded AISI 631,RH1050 failed when stressed to 75% of its yield strength and exposed at the 2,500-foot depth. Specimens with circular weld beads also failed when exposed at depth. The cracks originated at the outside edge of the weld beads and propagated circumferentially in both directions either at the edge of the weld bead or in the heat-affected zone.

Specimens of alloy AISI 632,RH100 with a transverse butt weld did not fail by stress corrosion when stressed to 75% of its yield strength and exposed either at the surface or at depth. However, a specimen with a circular weld failed during 402 days of exposure at the 2,500-foot depth. The origin of the crack was on the outside edge of the weld bead, and it propagated circumferentially in both directions in the heat-affected zone.

Alloys AISI 634,CRT; AISI 635; ASTM XM16,H950 and H1050; AL362,H950 and H1050; and alloy 18Cr-14Mn-0.5N were not susceptible to stress corrosion under the conditions of these tests.

Alloy PH14-8Mo,SRH950 with a transverse butt weld failed by stress corrosion cracking when stressed to 50% of its yield strength and exposed at depth.

Specimens of 15-7AMV in the A, RH1150, and RH950 tempers failed by stress corrosion cracking when stressed at 35, 50, and 75% of their respective yield strengths and exposed at depth. Alloy 15-7AMV,RH1150 failed when exposed at depth due to the stresses imposed by it being squeezed between insulators such that it was slightly bowed. Alloys of 15-7AMV,RH1150 and RH950 failed by stress corrosion when exposed at depth; the cracks originated at unreamed, drilled holes in the specimens.

5.4.6. Mechanical Properties

The effects of exposure on the mechanical properties of the precipitating-hardening stainless steels are given in Table 52. Generally, the mechanical properties of the precipitation-hardening stainless steels were adversely affected by exposure in seawater both at the surface and at depth.

5.5. MISCELLANEOUS STAINLESS STEELS

Included in this category are the case and specialty stainless steels which could not be included in the other classifications. Their higher nickel contents and the addition of molybdenum are to increase the range of protection of their passive films and to increase their r istance to pitting corrosion. Because these passive films are so much more resistant to destruction, any corrosion is localized in the form of crevice and pitting.

The chemical compositions of the miscellaneous stainless steels are given in Table 53, their corrosion rates and types of corrosion in Table 54, their stress corrosion behavior in Table 55, and the effect of exposure on their mechanical properties in Table 56.

These alloys were considerably more resistant to corrosion than the other alloys. There were two cases of crevice corrosion at depth of alloy 20Cb, with the deepest attack being 102 mils. There were also two cases each of crevice and pitting attack during surface exposure; 21 mils maximum for crevice corrosion, and 24 mils maximum for pitting corrosion.

Alloy 20Cb-3, a modified version of 20Cb (4% higher nickel content), was more resistant to corrosion by seawater and the bottom sediments than 20Cb. There was only one case of crevice corrosion (40 mils deep) at depth.

The corrosion of two cast versions of 20Cb, Ni-Cr-Cu-Mo numbers 1 and 2, was very similar to that of the 20Cb. There were isolated cases of crevice corrosion, the maximum depth of attack being 27 mils.

There was only incipient crevice corrosion on cast alloy Ni-Cr-Mo during exposure at the surface and at depth.

Cast alloy Ni-Cr-Mo-Si was not susceptible to corrosion by seawater during exposure either at the surface or at depth.

Cast alloy RL-35-100 was attacked by general and uniform types rather than by the localized types of corrosion. The corrosion rates were rather low, the maximum being 0.7 mil per year after 3 years of exposure at the 6,000-foot depth.

The corrosion behavior of these alloys was not affected by duration of exposure, depth of exposure, or changes in the concentration of oxygen in seawater.

As shown in Table 55, alloy 20Cb was not susceptible to stress corrosion in seawater at depth.

The effects of exposure in seawater on the mechanical properties of alloy 20Cb are given in Table 56. The mechanical properties were not affected.

Table 36. Chemical Compositions of 200 Series Stainless Steels, Percent by Weight

Alloy	C	Mn	P	S	Si	Ni	Cr	Fe[a]	Source[b]
AISI 201	0.08	6.8	–	–	–	4.0	17.1	R	INCO (3)
AISI 201	0.14	7.0	–	0.009	–	4.5	16.5	R	NADC (7)
AISI 202	0.09	7.6	–	–	–	4.5	17.8	R	INCO (3)
AISI 202	0.13	7.9	–	0.007	–	5.2	17.0	R	NADC (7)

[a]R = remainder.

[b]Numbers refer to references at end of report.

Table 37. Corrosion Rates and Types of Corrosion of 200 Series Stainless Steels

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion				Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Type[b]	
AISI 201	W	123	5,640	<0.1	0	I	I-C	INCO (3)
AISI 201	W	123	5,640	<0.1	0	0	NC	NADC (7)
AISI 201	S	123	5,640	<0.1	0	0	NC	INCO (3)
AISI 201	W	403	6,780	<0.1	0	I	I-C	INCO (3)
AISI 201	W	403	6,780	–	–	S	S-C	NADC (7)
AISI 201[d]	W	403	6,780	–	–	–	WB (NC)	NADC (7)
AISI 201	S	403	6,780	<0.1	0	2	C	INCO (3)
AISI 201	W	751	5,640	<0.1	0	I	I-C	INCO (3)
AISI 201	W	751	5,640	–	–	S	S-C	NADC (7)
AISI 201	S	751	5,640	<0.1	0	0	NC	INCO (3)
AISI 201	W	1,064	5,300	<0.1	0	I	I-C	INCO (3)
AISI 201	S	1,064	5,300	0.5	50	I	I-C; P (PR)	INCO (3)
AISI 201	W	197	2,340	<0.1	0	4	C	INCO (3)
AISI 201	W	197	2,340	–	–	S	S-C	NADC (7)
AISI 201	S	197	2,340	<0.1	0	3	C	INCO (3)
AISI 201	W	402	2,370	<0.1	0	1	C	INCO (3)
AISI 201	W	402	2,370	–	–	S	S-C; WB (S-C)	NADC (7)
AISI 201	S	402	2,370	<0.1	0	2	C	INCO (3)
AISI 201	W	182	5	<0.1	0	I	I-C	INCO (3)
AISI 201	W	366	5	0.6	0	0	S-E	INCO (3)
AISI 202	W	123	5,640	<0.1	0	0	NC	INCO (3)
AISI 202	W	123	5,640	<0.1	–	–	NC	NADC (7)
AISI 202	S	123	5,640	<0.1	0	0	NC	INCO (3)
AISI 202	W	403	6,780	<0.1	0	I	I-C	INCO (3)
AISI 202	S	403	6,780	<0.1	0	I	I-C	INCO (3)
AISI 202	W	751	5,640	<0.1	0	I	I-C	INCO (3)
AISI 202	S	751	5,640	<0.1	0	I	I-C	INCO (3)

Continued

Table 37. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion				Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Type[b]	
AISI 202	W	1,064	5,300	<0.1		0	NC	INCO (3)
AISI 202	S	1,064	5,300	<0.1	0	50	C (PR)	INCO (3)
AISI 202	W	197	2,340	<0.1	0	I	I-C	INCO (3)
AISI 202	S	197	2,340	<0.1	0	I	I-C	INCO (3)
AISI 202	W	402	2,370	<0.1	0	17	C	INCO (3)
AISI 202	S	402	2,370	<0.1	17	0	P	INCO (3)
AISI 202	W	182	5	0.6	50	50	C (PR); P (PR)	INCO (3)
AISI 202	W	366	5	0.5	50	50	C (PR); P (PR)	INCO (3)

[a]W = Totally exposed in seawater on sides of structure; S = Exposed in base of structure so that the lower portions of the specimen were embedded in the bottom sediments.

[b]Symbols for types of corrosion:

C = Crevice
I = Incipient
NC = No visible corrosion
P = Pitting
PR = Perforated
S = Severe
WB = Weld bead

[c]Numbers refer to references at end of report.

[d]Welded.

Table 38. Stress Corrosion of 200 Series Stainless Steels

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed	Source[a]
AISI 201	22	30	403	6,780	3	0	NADC (7)
AISI 201	55	75	403	6,780	3	0	NADC (7)
AISI 201, sensitized	55	75	403	6,780	3	0	NADC (7)
AISI 201	22	30	197	2,340	3	0	NADC (7)
AISI 201	55	75	197	2,340	3	0	NADC (7)
AISI 201, sensitized	55	75	197	2,340	3	0	NADC (7)
AISI 201	22	30	402	2,370	3	0	NADC (7)
AISI 201	55	75	402	2,370	3	0	NADC (7)
AISI 201, sensitized	22	30	402	2,370	3	0	NADC (7)
AISI 201, sensitized	55	75	402	2,370	3	0	NADC (7)

[a]Numbers refer to references at end of report.

Table 39. Changes in the Mechanical Properties of 200 Series Stainless Steels Due to Corrosion

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[b]
				Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
AISI 201	W	123	5,640	120	+3	73	0	48	+6	NADC (7)
AISI 201	W	751	5,640	120	+2	73	-10	48	+4	NADC (7)
AISI 201	W	197	2,340	120	0	73	-4	48	-8	NADC (7)
AISI 201	W	402	2,370	120	-7	73	-34	48	+35	NADC (7)
AISI 201, welded	W	402	2,370	120	-6	73	-32	48	+29	NADC (7)
AISI 201, sensitized	W	402	2,370		-8		-34		+33	NADC (7)
AISI 202	W	123	5,640	106	+6	—	0	55	0	NADC (7)
AISI 202	W	751	5,640	106	-8	—	-31	—	—	NADC (7)

[a]W = Totally exposed in seawater on sides of structure; S = Exposed in base of structure so that the lower portions of the specimen were embedded in the bottom sediments.

[b]Numbers refer to references at end of report.

Table 40. Chemical Compositions of 300 Series Stainless Steels, Percent by Weight

Alloy	C	Mn	P	S	Si	Ni	Cr	Mo	Other	Fe[a]	Source[b]
AISI 301	0.11	1.17	0.025	0.021	0.34	6.73	17.4	–	–	R	CEL (4)
AISI 301	0.08	1.00	–	0.008	–	7.50	17.50	–	–	R	NADC (7)
AISI 302	0.06	1.05	0.020	0.013	0.60	9.33	18.21	–	–	R	CEL (4)
AISI 302	0.11	1.36	–	–	–	9.9	17.3	0.12	0.26 Cu	R	INCO (3)
AISI 304	0.06	1.73	0.024	0.013	0.43	10.0	18.8	–	–	R	CEL (4)
AISI 304	0.05	1.73	0.020	0.012	0.52	9.55	18.2	0.18	–	R	CEL (4)
AISI 304	0.06	1.46	–	–	–	9.5	18.2	0.34	0.16 Cu	R	INCO (3)
AISI 304	–	–	–	–	–	10.0	19.0	–	–	R	MEL (5)
AISI 304	0.07	–	–	0.019	–	8.90	18.2	0.30	0.19 Cu	R	NADC (7)
AISI 304L	0.03	1.24	0.028	0.023	0.68	10.20	18.7	–	–	R	CEL (4)
AISI 304L	0.02	1.45	–	–	–	9.5	17.9	–	–	R	INCO (3)
AISI 304L	0.03	1.80	–	0.015	–	10.00	18.90	–	0.2 V	R	NADC (7)
AISI 309	0.1	1.60	–	–	–	12.7	23.3	–	–	R	INCO (3)
AISI 310	0.04	1.78	–	–	–	20.9	25.3	–	–	R	INCO (3)
AISI 311	0.2	2.0	–	–	–	19.0	25.0	–	–	R	INCO (3)
AISI 316	0.06	1.61	0.021	0.016	0.40	13.60	18.3	2.41	–	R	CEL (4)
AISI 316	0.05	1.73	–	–	–	13.2	17.2	2.60	–	R	INCO (3)
AISI 316	0.05	1.40	0.01	–	–	12.90	16.40	2.15	–	R	NADC (7)
AISI 316L	0.03	1.29	0.015	0.019	0.51	13.10	17.5	2.32	–	R	CEL (4)
AISI 316L	0.02	1.31	0.013	0.015	0.47	13.70	17.9	2.76	–	R	CEL (4)
AISI 316L	0.02	1.78	–	–	–	13.6	17.7	2.15	–	R	INCO (3)
AISI 316L[c]											NADC (7)
AISI 317	0.05	1.61	–	–	–	13.6	18.7	3.3	–	R	INCO (3)
AISI 321	0.06	2.0	–	–	–	10.5	18.5	–	–	R	INCO (3)
AISI 321	–	1.37	–	–	–	9.85	17.12	–	–	R	NADC (7)
AISI 325	0.03	0.7	–	–	–	23.5	9.0	–	–	R	INCO (3)
AISI 329	0.07	0.46	–	–	–	4.4	27.0	1.40	–	R	INCO (3)
AISI 330	0.20	–	–	–	–	34.5	15.0	–	–	R	INCO (3)
AISI 347	0.04	1.19	–	–	–	11.3	18.1	–	–	R	INCO (3)
AISI 347	–	1.77	–	–	–	10.97	18.00	0.24	–	R	NADC (7)

[a]R = remainder.

[b]Numbers refer to references at end of report.

[c]No values given.

Table 41. Corrosion Rates and Types of Corrosion of 300 Series Stainless Steels

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Maximum Tunnel Length (mils)	Type[b]	
AISI 301	W	123	5,640	0.3	0	SL	1,200	SL-C; T	CEL (4)
AISI 301	W	123	5,640	<0.1	0	SL	–	SL-C	NADC (7)
AISI 301	S	123	5,640	0.7	0	SL	750	SL-C; T	CEL (4)
AISI 301	W	403	6,780	1.4	103	15	2,450	C; T; P (PR)	CEL (4)
AISI 301	S	403	6,780	1.6	103	25	4,000	C; T; P (PR)	CEL (4)
AISI 301	W	751	5,640	1.7	103	0	6,000	E; T; P (PR)	CEL (4)
AISI 301	S	751	5,640	1.0	103	0	10,500	E; T; P (PR)	CEL (4)
AISI 301	W	1,064	5,300	0.4	103	0	11,000	E; T; P (PR)	CEL (4)
AISI 301	S	1,064	5,300	1.0	103	0	6,500	E; T; P (PR)	CEL (4)
AISI 301	W	197	2,340	0.3	0	SL	1,250	SL-C; T	CEL (4)
AISI 301	S	197	2,340	0.3	0	SL	1,400	SL-C; T	CEL (4)
AISI 301	W	402	2,370	0.5	103	0	2,500	T; P (PR)	CEL (4)
AISI 301	S	402	2,370	0.6	103	0	2,500	T; P (PR)	CEL (4)
AISI 301	W	181	5	1.9	103	0	2,200	S-E; T; P (PR)	CEL (4)
AISI 301	W	398	5	2.3	103	0	1,150	T; P (PR)	CEL (4)
AISI 301	W	588	5	1.7	103	50	1,500	C; T; P (PR)	CEL (4)
AISI 302	W	123	5,640	<0.1	0	SL	0	SL-C	CEL (4)
AISI 302	W	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 302	S	123	5,640	<0.1	0	SL	0	SL-C	CEL (4)
AISI 302	S	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 302	W	403	6,780	<0.1	0	18	0	C	CEL (4)
AISI 302	W	403	6,780	<0.1	0	I	–	I-C	INCO (3)
AISI 302	S	403	6,780	<0.1	0	23	0	C	CEL (4)
AISI 302	S	403	6,780	<0.1	0	I	–	I-C	INCO (3)
AISI 302	W	751	5,640	<0.1	0	21	0	C	CEL (4)
AISI 302	W	751	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 302	S	751	5,640	<0.1	0	I	6,000	I-C; E; T	CEL (4)

Continued

Table 41. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Maximum Tunnel Length (mils)	Type[b]	
AISI 302	S	751	5,640	<0.1	0	I	–	I-C	INCO (3)
AISI 302	W	1,064	5,300	<0.1	0	0	–	NC	INCO (3)
AISI 302	S	1,064	5,300	<0.1	50	50	–	C (PR); P (PR)	INCO (3)
AISI 302	W	197	2,340	<0.1	53	53	1,375	C;(PR); P (PR); T	CEL (4)
AISI 302	W	197	2,340	<0.1	0	I	–	I-C	INCO (3)
AISI 302	S	197	2,340	<0.1	0	20	250	C-T	CEL (4)
AISI 302	S	197	2,340	<0.1	0	I	–	I-C	INCO (3)
AISI 302	W	402	2,370	<0.1	0	18	6,000	C-T	CEL (4)
AISI 302	W	402	2,370	<0.1	0	I	–	I-C	INCO (3)
AISI 302	S	402	2,370	<0.1	0	53	0	C	CEL (4)
AISI 302	S	402	2,370	<0.1	0	I	–	I-C	INCO (3)
AISI 302	W	181	5	0.9	53	0	4,950	E; P (PR); T	CEL (4)
AISI 302	W	181	5	<0.1	15	7	–	C; P	INCO (3)
AISI 302	W	366	5	<0.1	I	I	–	I-C; I-P	INCO (3)
AISI 302	W	398	5	0.4	53	53	5,400	C (PR); E; P (PR); T	CEL (4)
AISI 302	W	588	5	0.5	53	53	5,500	C (PR); P (PR); T	CEL (4)
AISI 304	W	123	5,640	<0.1	0	0	450	T	CEL (4)
AISI 304	W	123	5,640	<0.1	0	I	–	I-C	INCO (3)
AISI 304	W	123	5,640	1.1	0	31	–	C	MEL (5)
AISI 304	S	123	5,640	<0.1	0	0	0	NC	CEL (4)
AISI 304	S	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 304	W	403	6,780	0.5	210	0	2,000	E; P (PR); T	CEL (4)
AISI 304	W	403	6,780	<0.1	0	I	–	I-C	INCO (3)
AISI 304	W	403	6,780	–	–	–	–	S-C; WB (NC)	NADC (7)
AISI 304	S	403	6,780	<0.1	0	0	0	SL-E	CEL (4)
AISI 304	S	403	6,780	<0.1	0	I	–	I-C	INCO (3)
AISI 304	W	751	5,640	0.5	210	0	1,600	P (PR); T	CEL (4)

Continued

Table 41. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Maximum Tunnel Length (mils)	Type[b]	
AISI 304	W	751	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 304	W	751	5,640	1.6	S	125	–	C (PR); E; S-P	MEL (5)
AISI 304	S	751	5,640	<0.1	0	13	–	C	INCO (3)
AISI 304	W	1,064	5,300	<0.1	13	74	1,750	C; E; P; T	CEL (4)
AISI 304	W	1,064	5,300	<0.1	0	I	–	I-C	INCO (3)
AISI 304	W	1,064	5,300	1.0	S	125	–	C (PR); S-E; S-P	MEL (5)
AISI 304	W	1,064	5,300	–	–	–	–	S-C; S-T	NADC (7)
AISI 304	S	1,064	5,300	<0.1	210	29	1,500	C; E; P (PR); T	CEL (4)
AISI 304	S	1,064	5,300	<0.1	0	50	–	C (PR)	INCO (3)
AISI 304	W	197	2,340	0.3	0	11	950	C; E; T	CEL (4)
AISI 304	W	197	2,340	<0.1	0	I	–	I-C	INCO (3)
AISI 304	W	197	2,340	–	–	–	–	S-C	NADC (7)
AISI 304	S	197	2,340	<0.1	0	SL	1,000	SL-C; E; T	CEL (4)
AISI 304	S	197	2,340	<0.1	0	I	–	I-C	INCO (3)
AISI 304	W	402	2,370	0.4	210	0	2,000	E; P (PR); T	CEL (4)
AISI 304	W	402	2,370	<0.1	0	13	–	C	INCO (3)
AISI 304	W	402	2,370	–	–	–	–	S-C; S-T; WB (NC)	NADC (7)
AISI 304	S	402	2,370	0.1	0	0	1,250	S-E; T	CEL (4)
AISI 304	S	402	2,370	<0.1	0	4	–	C	INCO (3)
AISI 304	W	181	5	1.8	210	0	500	E; P (PR); T	CEL (4)
AISI 304	W	181	5	1.3	45	20	–	C; P	INCO (3)
AISI 304	W	366	5	0.4	34	33	–	C; P	INCO (3)
AISI 304	W	386[d]	5	0.6	63	63	–	C (PR); E; P (PR)	MEL (5)
AISI 304	W	540	5	0.7	42	103	180	C; P; T	CEL (4)
AISI 304	W	588	5	0.5	0	138	110	C; T	CEL (4)
AISI 304[e]	W	123	5,640	0.7	0	50	–	C (PR)	INCO (3)
AISI 304[e]	S	123	5,640	0.8	0	37	–	C	INCO (3)

Continued

Table 41. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Maximum Tunnel Length (mils)	Type[b]	
AISI 304[c]	W	403	6,780	0.7	0	50	–	C (PR)	INCO (3)
AISI 304[e]	W	403	6,780	–	–	–	–	S-C; S-T; WB (NC)	NADC (7)
AISI 304[c]	S	403	6,780	0.4	0	2	–	C	INCO (3)
AISI 304[e]	W	751	5,640	0.5	50	50	–	C (PR); P (PR)	INCO (3)
AISI 304[e]	S	751	5,640	0.2	0	50	–	C (PR)	INCO (3)
AISI 304[e]	W	1,064	5,300	0.4	50	50	–	C (PR); P (PR)	INCO (3)
AISI 304[e]	W	1,064	5,300	–	–	–	–	S-C; S-T	NADC (7)
AISI 304[e]	S	1,064	5,300	0.2	50	50	–	C (PR); P (PR)	INCO (3)
AISI 304[e]	W	197	2,340	0.6	0	50	–	C (PR)	INCO (3)
AISI 304[e]	W	197	2,340	–	–	–	–	S-C	NADC (7)
AISI 304[e]	S	197	2,340	<0.1	0	I	–	I-C	INCO (3)
AISI 304[e]	W	402	2,370	0.3	0	50	–	C (PR)	INCO (3)
AISI 304[e]	W	402	2,370	–	–	–	–	S-C; S-T; WB (NC)	NADC (7)
AISI 304[e]	S	402	2,370	<0.1	0	17	–	C	INCO (3)
AISI 304[e]	W	181	5	1.1	50	50	–	C (PR); P (PR)	INCO (3)
AISI 304[e]	W	366	5	1.2	50	50	–	C (PR); P (PR)	INCO (3)
AISI 304L	W	123	5,640	0.2	0	SL	200	SL-C; T	CEL (4)
AISI 304L	W	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 304L	S	123	5,640	<0.1	0	SL	0	SL-C; T	CEL (4)
AISI 304L	S	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 304L	W	403	6,780	<0.1	115	12	4,850	C; E; P (PR); T	CEL (4)
AISI 304L	W	403	6,780	<0.1	0	I	–	I-C	INCO (3)
AISI 304L	W	403	6,780	–	–	–	–	S-C; S-T; WB (NC)	NADC (7)
AISI 304L	S	403	6,780	0.1	0	29	1,000	C; E; T	CEL (4)
AISI 304L	S	403	6,780	<0.1	0	2	–	C	INCO (3)
AISI 304L	W	751	5,640	0.3	115	0	4,000	P (PR); T	CEL (4)
AISI 304L	W	751	5,640	<0.1	0	0	–	NC	INCO (3)

Continued

Table 41. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Maximum Tunnel Length (mils)	Type[b]	
AISI 304L	S	751	5,640	0.6	0	45	1,000	C; T	CEL (4)
AISI 304L	S	751	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 304L	W	1,064	5,300	0.2	115	115	4,000	C (PR); E; P (PR); T	CEL (4)
AISI 304L	W	1,064	5,300	<0.1	0	I	–	I-C	INCO (3)
AISI 304L	W	1,064	5,300	–	–	–	–	SL-R	NADC (7)
AISI 304L	S	1,064	5,300	0.1	115	0	3,000	P (PR); T	CEL (4)
AISI 304L	S	1,064	5,300	0.2	50	50	–	C (PR); P (PR)	INCO (3)
AISI 304L	W	197	2,340	0.2	0	8	800	C; T	CEL (4)
AISI 304L	W	197	2,340	<0.1	0	I	–	I-C	INCO (3)
AISI 304L	W	197	2,340	–	–	–	–	S-C	NADC (7)
AISI 304L	S	197	2,340	0.1	0	18	0	C	CEL (4)
AISI 304L	S	197	2,340	<0.1	0	I	–	I-C	INCO (3)
AISI 304L	W	402	2,370	0.4	115	0	3,000	P (PR); T	CEL (4)
AISI 304L	W	402	2,370	<0.1	0	I	–	I-C	INCO (3)
AISI 304L	W	402	2,370	–	–	–	–	SL-C; SL-R; WB (L); HAZ (R&T)	NADC (7)
AISI 304L	S	402	2,370	0.2	0	0	1,000	T	CEL (4)
AISI 304L	S	402	2,370	<0.1	0	I	–	I-C	INCO (3)
AISI 304L	W	181	5	0.7	97	0	400	E; P; T	CEL (4)
AISI 304L	W	181	5	<0.1	0	I	–	I-C	INCO (3)
AISI 304L	W	366	5	0.5	50	0	–	P (PR)	INCO (3)
AISI 304L	W	398	5	1.0	115	0	1,100	E; P (PR); T	CEL (4)
AISI 304L	W	540	5	0.7	115	115	1,500	C (PR); E; P (PR); T	CEL (4)
AISI 309	W	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 309	S	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 309	W	403	6,780	<0.1	0	I	–	I-C	INCO (3)

Continued

Table 41. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Maximum Tunnel Length (mils)	Type[b]	
AISI 309	S	403	6,780	<0.1	0	1	–	I-C	INCO (3)
AISI 309	W	751	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 309	S	751	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 309	W	1,064	5,300	<0.1	0	1	–	I-C	INCO (3)
AISI 309	S	1,064	5,300	<0.1	0	1	–	I-C	INCO (3)
AISI 309	W	197	2,340	<0.1	0	1	–	I-C	INCO (3)
AISI 309	S	197	2,340	<0.1	0	1	–	I-C	INCO (3)
AISI 309	W	402	2,370	<0.1	0	1	–	I-C	INCO (3)
AISI 309	S	402	2,370	<0.1	0	1	–	I-C	INCO (3)
AISI 309	W	181	5	<0.1	0	33	–	C	INCO (3)
AISI 309	W	366	5	<0.1	0	1	–	I-C	INCO (3)
AISI 310	W	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 310	S	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 310	W	403	6,780	<0.1	0	1	–	I-C	INCO (3)
AISI 310	S	403	6,780	<0.1	0	1	–	I-C	INCO (3)
AISI 310	W	751	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 310	S	751	5,640	<0.1	0	1	–	I-C	INCO (3)
AISI 310	W	1,064	5,300	<0.1	0	1	–	I-C	INCO (3)
AISI 310	S	1,064	5,300	<0.1	0	1	–	I-C	INCO (3)
AISI 310	W	197	2,340	<0.1	0	1	–	I-C	INCO (3)
AISI 310	S	197	2,340	<0.1	0	1	–	I-C	INCO (3)
AISI 310	W	402	2,370	<0.1	0	14	–	C	INCO (3)
AISI 310	S	402	2,370	<0.1	0	2	–	C	INCO (3)
AISI 310	W	181	5	<0.1	0	1	–	I-C	INCO (3)
AISI 310	W	366	5	<0.1	0	50	–	C (PR)	INCO (3)
AISI 311	W	123	5,640	<0.1	0	0	–	NC	INCO (3)

Continued

Table 41. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Maximum Tunnel Length (mils)	Type[b]	
AISI 311	S	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 311	W	403	6,780	<0.1	0	I	–	I-C	INCO (3)
AISI 311	S	403	6,780	<0.1	0	I	–	I-C	INCO (3)
AISI 311	W	751	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 311	S	751	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 311	W	1,064	5,300	<0.1	0	I	–	I-C	INCO (3)
AISI 311	S	1,064	5,300	<0.1	0	5	–	C	INCO (3)
AISI 311	W	197	2,340	<0.1	0	I	–	I-C	INCO (3)
AISI 311	S	197	2,340	<0.1	0	2	–	C	INCO (3)
AISI 311	W	402	2,370	<0.1	0	6	–	C	INCO (3)
AISI 311	S	402	2,370	<0.1	0	I	–	I-C	INCO (3)
AISI 311	W	181	5	0.5	28	50	–	C (PR); P	INCO (3)
AISI 311	W	366	5	<0.1	I	I	–	I-C; I-P	INCO (3)
AISI 316	W	123	5,640	<0.1	0	0	10	SL-E; SL-T	CEL (4)
AISI 316	W	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 316	S	123	5,640	<0.1	0	0	0	SL-E	CEL (4)
AISI 316	S	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 316	W	403	6,780	<0.1	0	0	0	NC	CEL (4)
AISI 316	W	403	6,780	<0.1	0	I	–	I-C	INCO (3)
AISI 316	W	403	6,780	–	–	–	–	C; WB (NC)	NADC (7)
AISI 316	S	403	6,780	<0.1	0	5	0	C	CEL (4)
AISI 316	S	403	6,780	<0.1	0	I	–	I-C	INCO (3)
AISI 316	W	751	5,640	<0.1	0	0	0	NC	CEL (4)
AISI 316	W	751	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 316	S	751	5,640	<0.1	0	0	0	NC	CEL (4)
AISI 316	S	751	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 316	W	1,064	5,300	0.2	21	0	0	P	CEL (4)

Continued

Table 41. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Maximum Tunnel Length (mils)	Type[b]	
AISI 316	W	1,064	5,300	<0.1	0	1	–	C	INCO (3)
AISI 316	S	1,064	5,300	0.2	0	I	0	I-C	CEL (4)
AISI 316	S	1,064	5,300	<0.1	0	I	–	I-C	INCO (3)
AISI 316	W	197	2,340	<0.1	0	0	0	NC	CEL (4)
AISI 316	W	197	2,340	<0.1	0	0	–	NC	INCO (3)
AISI 316	W	197	2,340	0.1	0	SL	0	SL-C; SL-R (WB&HAZ)	NADC (7)
AISI 316	S	197	2,340	<0.1	0	0	0	NC	CEL (4)
AISI 316	S	197	2,340	<0.1	0	I	–	I-C	INCO (3)
AISI 316	W	402	2,370	0.1	230	0	500	E; P (PR); T	CEL (4)
AISI 316	W	402	2,370	<0.1	0	I	–	I-C	INCO (3)
AISI 316	W	402	2,370	0.1	–	–	–	S-C; SC-P; WB (NC)	NADC (7)
AISI 316	S	402	2,370	<0.1	I	0	0	I-P	CEL (4)
AISI 316	S	402	2,370	<0.1	0	I	–	I-C	INCO (3)
AISI 316	W	181	5	1.3	230	0	1,250	E; P (PR); T	CEL (4)
AISI 316	W	181	5	<0.1	0	I	–	I-C	INCO (3)
AISI 316	W	366	5	<0.1	0	0	–	NC	INCO (3)
AISI 316	W	398	5	0.4	154	20	1,350	C; E; P; T	CEL (4)
AISI 316	W	540	5	0.3	0	63	70	C; T	CEL (4)
AISI 316	W	588	5	0.2	0	130	1,500	C; T (PR)	CEL (4)
AISI 316[e]	W	123	5,640	<0.1	0	I	–	I-C	INCO (3)
AISI 316[e]	S	123	5,640	0.1	0	21	–	C	INCO (3)
AISI 316[e]	W	403	6,780	<0.1	0	I	–	I-C	INCO (3)
AISI 316[e]	W	403	6,780	–	–	–	–	MD-C; WB (NC)	NADC (7)
AISI 316[e]	S	403	6,780	<0.1	0	2	–	C	INCO (3)
AISI 316[e]	W	751	5,640	1.5	50	50	–	C (PR); P (PR)	INCO (3)
AISI 316[e]	S	751	5,640	0.3	0	50	–	C (PR)	INCO (3)
AISI 316[e]	W	1,064	5,300	<0.1	0	15	–	C	INCO (3)

Continued

Table 41. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Maximum Tunnel Length (mils)	Type[b]	
AISI 316[e]	S	1,064	5,300	<0.1	0	6	–	C	INCO (3)
AISI 316[e]	W	197	2,340	<0.1	0	8	–	C	INCO (3)
AISI 316[e]	S	197	2,340	<0.1	0	I	–	I-C	INCO (3)
AISI 316[e]	W	402	2,370	<0.1	0	8	–	C	INCO (3)
AISI 316[e]	W	402	2,370	0.1	–	–	–	S-C; SC-P; WB (NC)	NADC (7)
AISI 316[e]	S	402	2,370	<0.1	0	I	–	I-C	INCO (3)
AISI 316[e]	W	181	5	0.8	7	38	–	C; P	INCO (3)
AISI 316[e]	W	366	5	0.6	50	50	–	C (PR); P (PR)	INCO (3)
AISI 316L	W	123	5,640	<0.1	0	SL	0	SL-C	CEL (4)
AISI 316L	W	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 316L	S	123	5,640	<0.1	0	SL	0	SL-C	CEL (4)
AISI 316L	S	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 316L	W	403	6,780	<0.1	0	0	0	NC	CEL (4)
AISI 316L	W	403	6,780	<0.1	0	I	–	I-C	INCO (3)
AISI 316L	W	403	6,780	<0.1	–	–	–	C; SL-R; WB (NC)	NADC (7)
AISI 316L	S	403	6,780	<0.1	0	0	0	NC	CEL (4)
AISI 316L	S	403	6,780	<0.1	0	I	–	I-C	INCO (3)
AISI 316L	W	751	5,640	<0.1	0	13	0	C	CEL (4)
AISI 316L	W	751	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 316L	S	751	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 316L	W	1,064	5,300	<0.1	0	25	0	C	CEL (4)
AISI 316L	W	1,064	5,300	<0.1	0	I	–	I-C	INCO (3)
AISI 316L	S	1,064	5,300	<0.1	0	20	0	C	CEL (4)
AISI 316L	S	1,064	5,300	<0.1	0	I	–	I-C	INCO (3)
AISI 316L	W	197	2,340	<0.1	0	18	0	C	CEL (4)
AISI 316L	W	197	2,340	<0.1	0	8	–	C	INCO (3)
AISI 316L	S	197	2,340	<0.1	0	12	0	C	CEL (4)

Continued

Table 41. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Maximum Tunnel Length (mils)	Type[b]	
AISI 316L	S	197	2,340	<0.1	0	I	–	I-C	INCO (3)
AISI 316L	W	402	2,370	<0.1	0	0	0	NC	CEL (4)
AISI 316L	W	402	2,370	<0.1	0	I	–	I-C	INCO (3)
AISI 316L	W	402	2,370	–	–	–	–	G; WB (S-L; T)	NADC (7)
AISI 316L	S	402	2,370	<0.1	0	45	0	C	CEL (4)
AISI 316L	S	402	2,370	<0.1	0	I	–	I-C	INCO (3)
AISI 316L	W	181	5	0.3	125	0	1,400	E; P (PR); T	CEL (4)
AISI 316L	W	181	5	<0.1	0	25	–	C	INCO (3)
AISI 316L	W	366	5	<0.1	0	I	–	I-C	INCO (3)
AISI 316L	W	398	5	<0.1	0	0	0	SL-E	CEL (4)
AISI 317	W	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 317	S	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 317	W	403	6,780	<0.1	0	I	–	I-C	INCO (3)
AISI 317	S	403	6,780	<0.1	0	I	–	I-C	INCO (3)
AISI 317	W	751	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 317	S	751	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 317	W	1,064	5,300	<0.1	0	I	–	I-C	INCO (3)
AISI 317	S	1,064	5,300	<0.1	0	0	–	NC	INCO (3)
AISI 317	W	197	2,340	<0.1	0	I	–	I-C	INCO (3)
AISI 317	S	197	2,340	<0.1	0	I	–	I-C	INCO (3)
AISI 317	W	402	2,370	<0.1	0	I	–	I-C	INCO (3)
AISI 317	S	402	2,370	<0.1	0	I	–	I-C	INCO (3)
AISI 317	W	181	5	<0.1	0	0	–	NC	INCO (3)
AISI 317	W	366	5	<0.1	0	I	–	I-C	INCO (3)
AISI 321	W	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 321	W	123	5,640	<0.1	0	0	–	NC	NADC (7)

Continued

Table 41. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Maximum Tunnel Length (mils)	Type[b]	
AISI 321	S	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 321	W	403	6,780	<0.1	0	I	–	I-C	INCO (3)
AISI 321	W	403	6,780	<0.1	–	–	–	T; HAZ	NADC (7)
AISI 321	S	403	6,780	<0.1	0	I	–	I-C	INCO (3)
AISI 321	W	751	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 321	W	751	5,640	1.5	–	–	–	SL-C; SC-R	NADC (7)
AISI 321	S	751	5,640	<0.1	0	I	–	I-C	INCO (3)
AISI 321	W	1,064	5,300	<0.1	0	I	–	I-C	INCO (3)
AISI 321	W	1,064	5,300	<0.1	–	–	–	SL-C; SC-R	NADC (7)
AISI 321	S	1,064	5,300	<0.1	0	0	–	NC	INCO (3)
AISI 321	W	197	2,340	<0.1	0	I	–	I-C	INCO (3)
AISI 321	W	197	2,340	0.2	–	–	–	S-C; SL-P; S-T	NADC (7)
AISI 321	S	197	2,340	<0.1	0	2	–	C	INCO (3)
AISI 321	W	402	2,370	0.2	0	30	–	C (PR)	INCO (3)
AISI 321	W	402	2,370	–	–	–	–	SL-C; SL-R; HAZ (P)	NADC (7)
AISI 321	S	402	2,370	<0.1	0	I	–	I-C	INCO (3)
AISI 321	W	181	5	<0.1	0	2	–	C	INCO (3)
AISI 321	W	366	5	<0.1	22	0	–	P	INCO (3)
AISI 325	W	123	5,640	4.2	11	0	–	P	INCO (3)
AISI 325	S	123	5,640	3.3	13	0	–	P	INCO (3)
AISI 325	W	403	6,780	4.6	14	0	–	P	INCO (3)
AISI 325	S	403	6,780	1.3	0	3	–	C	INCO (3)
AISI 325	W	751	5,640	2.1	0	0	–	G	INCO (3)
AISI 325	S	751	5,640	3.5	0	0	–	NU	INCO (3)
AISI 325	W	1,064	5,300	1.1	0	0	–	G	INCO (3)
AISI 325	S	1,064	5,300	1.3	0	0	–	G	INCO (3)
AISI 325	W	197	2,340	2.8	12	0	–	P	INCO (3)

Continued

Table 41. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion: Rate (mpy)	Corrosion: Maximum Pit Depth (mils)	Corrosion: Crevice Depth[b] (mils)	Corrosion: Maximum Tunnel Length (mils)	Corrosion: Type[b]	Source[c]
AISI 325	S	197	2,340	<0.1	0	2	–	C	INCO (3)
AISI 325	W	402	2,370	1.9	0	0	–	G	INCO (3)
AISI 325	S	402	2,370	0.3	0	0	–	G	INCO (3)
AISI 325	W	181	5	10.0	0	0	–	G	INCO (3)
AISI 325	W	366	5	6.3	16	12	–	C; P	INCO (3)
AISI 329	W	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 329	S	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 329	W	403	6,780	<0.1	0	0	–	NC	INCO (3)
AISI 329	S	403	6,780	<0.1	0	I	–	I-C	INCO (3)
AISI 329	W	751	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 329	S	751	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 329	W	1,064	5,300	<0.1	0	0	–	NC	INCO (3)
AISI 329	S	1,064	5,300	<0.1	0	0	–	NC	INCO (3)
AISI 329	W	197	2,340	<0.1	0	0	–	NC	INCO (3)
AISI 329	S	197	2,340	<0.1	0	0	–	NC	INCO (3)
AISI 329	W	402	2,370	<0.1	0	0	–	NC	INCO (3)
AISI 329	S	402	2,370	<0.1	0	0	–	NC	INCO (3)
AISI 329	W	181	5	<0.1	0	I	–	I-C	INCO (3)
AISI 329	W	366	5	<0.1	0	I	–	I-C	INCO (3)
AISI 330	W	123	5,640	<0.1	0	I	–	I-C	INCO (3)
AISI 330	S	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 330	W	403	6,780	<0.1	0	I	–	I-C	INCO (3)
AISI 330	S	403	6,780	<0.1	0	I	–	I-C	INCO (3)
AISI 330	W	751	5,640	<0.1	0	I	–	I-C	INCO (3)
AISI 330	S	751	5,640	<0.1	0	I	–	I-C	INCO (3)
AISI 330	W	1,064	5,300	<0.1	0	I	–	I-C	INCO (3)

Continued

Table 41. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Maximum Tunnel Length (mils)	Type[b]	
AISI 330	S	1,064	5,300	<0.1	0	3	–	C	INCO (3)
AISI 330	W	197	2,340	<0.1	0	I	–	I-C	INCO (3)
AISI 330	S	197	2,340	<0.1	0	I	–	I-C	INCO (3)
AISI 330	W	402	2,370	<0.1	0	30	–	C (PR)	INCO (3)
AISI 330	S	402	2,370	<0.1	0	2	–	C	INCO (3)
AISI 330	W	181	5	0.8	50	50	–	C (PR); P (PR)	INCO (3)
AISI 330	W	366	5	0.4	50	0	–	P (PR)	INCO (3)
AISI 347	W	123	5,640	<0.1	0	10	–	C	INCO (3)
AISI 347	W	123	5,640	<0.1	–	–	–	NC	NADC (7)
AISI 347	S	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 347	W	403	6,780	<0.1	0	I	–	I-C	INCO (3)
AISI 347	W	403	6,780	–	–	–	–	SL-R; WB (SL-R)	NADC (7)
AISI 347	S	403	6,780	<0.1	0	3	–	C	INCO (3)
AISI 347	W	751	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 347	W	751	5,640	–	–	–	–	SL-R	NADC (7)
AISI 347	S	751	5,640	<0.1	0	29	–	C	INCO (3)
AISI 347	W	1,064	5,300	<0.1	I	I	–	I-C; I-P	INCO (3)
AISI 347	S	1,064	5,300	<0.1	0	50	–	C (PR)	INCO (3)
AISI 347	W	197	2,340	<0.1	0	0	–	NC	INCO (3)
AISI 347	W	197	2,340	–	–	–	–	S-C; SL-R (WB&HAZ)	NADC (7)
AISI 347	S	197	2,340	<0.1	0	I	–	I-C	INCO (3)
AISI 347	W	402	2,370	<0.1	0	I	–	I-C	INCO (3)
AISI 347	W	402	2,370	–	–	–	–	SL-C; SL-R	NADC (7)
AISI 347	S	402	2,370	<0.1	0	2	–	C	INCO (3)
AISI 347	W	181	5	0.8	50	50	–	C (PR); P (PR)	INCO (3)
AISI 347	W	366	5	0.7	50	50	–	C (PR); P (PR)	INCO (3)

Continued

Table 41. Continued.

[a]W = Totally exposed in seawater on sides of structure; S = Exposed in base of structure so that the lower portions of the specimens were embedded in the bottom sediments.

[b]Symbols for types of corrosion:

C	= Crevice	P	= Pitting
E	= Edge	PR	= Perforation
HAZ	= Heat-affected zone	R	= Rust
I	= Incipient	S	= Severe
L	= Line	SC	= Scattered
MD	= Medium	SL	= Slight
NC	= No visible corrosion	T	= Tunnel
NU	= Nonuniform	WB	= Weld Bead

Numbers indicate maximum depth or length in mils.

[c]Numbers refer to references at end of report.

[d]Francis L. LaQue Corrosion Laboratory, INCO, Wrightsville Beach, NC

[e]Sensitized, heated 1 hr at 1,200°F, air cooled.

Table 42. Stress Corrosion of 300 Series Stainless Steels

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed	Source[a]
AISI 301	24	62	123	5,640	3	0	NADC (7)
AISI 301	32	82	123	5,640	3	0	NADC (7)
AISI 301	62	50	402	2,370	3	0	CEL (4)
AISI 301	94	75	402	2,370	3	0	CEL (4)
AISI 302	22	50	402	2,370	3	0	CEL (4)
AISI 302	33	75	402	2,370	3	0	CEL (4)
AISI 304	14	30	403	6,780	3	0	NADC (7)
AISI 304	35	75	403	6,780	3	0	NADC (7)
AISI 304, sensitized	14	30	403	6,780	3	0	NADC (7)
AISI 304, sensitized	35	75	403	6,780	3	0	NADC (7)
AISI 304	14	30	197	2,340	3	0	NADC (7)
AISI 304	35	75	197	2,340	3	0	NADC (7)
AISI 304, sensitized	35	75	197	2,340	3	0	NADC (7)
AISI 304	14	30	402	2,370	3	0	NADC (7)
AISI 304, sensitized	14	30	402	2,370	3	0	NADC (7)
AISI 304	16	50	402	2,370	3	0	CEL (4)
AISI 304	35	75	402	2,370	3	0	NADC (7)
AISI 304, sensitized	35	75	402	2,370	3	0	NADC (7)
AISI 304	25	75	402	2,370	3	0	CEL (4)
AISI 304L	14	35	123	5,640	3	0	CEL (4)
AISI 304L	20	50	123	5,640	3	0	CEL (4)
AISI 304L	30	75	123	5,640	3	0	CEL (4)
AISI 304L	13	30	403	6,780	3	0	NADC (7)
AISI 304L, sensitized	13	30	403	6,780	3	0	NADC (7)
AISI 304L	20	50	403	6,780	3	0	CEL (4)
AISI 304L	32	75	403	6,780	3	0	NADC (7)
AISI 304L, sensitized	32	75	403	6,780	3	0	NADC (7)
AISI 304L	30	75	403	6,780	3	0	CEL (4)
AISI 304L	14	35	751	5,640	3	0	CEL (4)
AISI 304L	20	50	751	5,640	3	0	CEL (4)
AISI 304L	30	75	751	5,640	3	0	CEL (4)
AISI 304L	13	30	197	2,340	3	0	NADC (7)
AISI 304L	20	50	197	2,340	3	0	CEL (4)
AISI 304L	32	75	197	2,340	3	0	NADC (7)
AISI 304L, sensitized	32	75	197	2,340	3	0	NADC (7)
AISI 304L	30	75	197	2,340	3	0	CEL (4)
AISI 304L	13	30	402	2,370	3	0	NADC (7)
AISI 304L	20	50	402	2,370	3	0	CEL (4)
AISI 304L	32	75	402	2,370	3	0	NADC (7)
AISI 304L, sensitized	32	75	402	2,370	3	0	NADC (7)
AISI 304L	30	75	402	2,370	3	0	CEL (4)

Continued

Table 42. Continued.

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed	Source[a]
AISI 316	14	30	403	6,780	3	0	NADC (7)
AISI 316, sensitized	14	30	403	6,780	3	0	NADC (7)
AISI 316	35	75	403	6,780	3	0	NADC (7)
AISI 316, sensitized	35	75	403	6,780	3	0	NADC (7)
AISI 316	14	30	197	2,340	3	0	NADC (7)
AISI 316	35	75	197	2,340	3	0	NADC (7)
AISI 316, sensitized	35	75	197	2,340	3	0	NADC (7)
AISI 316	14	30	402	2,370	3	0	NADC (7)
AISI 316, sensitized	14	30	402	2,370	3	0	NADC (7)
AISI 316	18	50	402	2,370	3	0	CEL (4)
AISI 316	35	75	402	2,370	3	0	NADC (7)
AISI 316, sensitized	35	75	402	2,370	3	0	NADC (7)
AISI 316	27	75	402	2,370	3	0	CEL (4)
AISI 316L	17	35	123	5,640	3	0	CEL (4)
AISI 316L	24	50	123	5,640	3	0	CEL (4)
AISI 316L	36	75	123	5,640	3	0	CEL (4)
AISI 316L	14	30	403	6,780	3	0	NADC (7)
AISI 316L	17	35	403	6,780	3	0	CEL (4)
AISI 316L	24	50	403	6,780	3	0	CEL (4)
AISI 316L	35	75	403	6,780	3	0	NADC (7)
AISI 316L, sensitized	35	75	403	6,780	3	0	NADC (7)
AISI 316L	36	75	403	6,780	3	0	CEL (4)
AISI 316L	17	35	751	5,640	3	0	CEL (4)
AISI 316L	24	50	751	5,640	3	0	CEL (4)
AISI 316L	36	75	751	5,640	3	0	CEL (4)
AISI 316L	17	35	197	2,340	3	0	CEL (4)
AISI 316L	24	50	197	2,340	3	0	CEL (4)
AISI 316L	36	75	197	2,340	3	0	CEL (4)
AISI 316L	24	50	402	2,370	3	0	CEL (4)
AISI 316L	36	75	402	2,370	3	0	CEL (4)
AISI 321	10	30	403	6,780	3	0	NADC (7)
AISI 321	25	75	403	6,780	3	0	NADC (7)
AISI 321, sensitized	25	75	403	6,780	3	0	NADC (7)
AISI 321	10	30	197	2,340	3	0	NADC (7)
AISI 321	25	75	197	2,340	3	0	NADC (7)
AISI 321, sensitized	25	75	197	2,340	3	0	NADC (7)
AISI 321	10	30	402	2,370	3	0	NADC (7)
AISI 321	25	75	402	2,370	3	0	NADC (7)
AISI 321, sensitized	25	75	402	2,370	3	0	NADC (7)

Continued

Table 42. Continued

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed	Source[a]
AISI 347	–	30	403	6,780	3	0	NADC (7)
AISI 347	–	75	403	6,780	3	0	NADC (7)
AISI 347, sensitized	–	75	403	6,780	3	0	NADC (7)
AISI 347	–	30	197	2,340	3	0	NADC (7)
AISI 347	–	75	197	2,340	3	0	NADC (7)
AISI 347, sensitized	–	75	197	2,340	3	0	NADC (7)
AISI 347	–	30	402	2,340	3	0	NADC (7)
AISI 347	–	75	402	2,370	3	0	NADC (7)
AISI 347, sensitized	–	75	402	2,370	3	0	NADC (7)

[a]Numbers refer to references at end of report.

Table 43. Changes in Mechanical Properties of the 300 Series Stainless Steels Due to Corrosion

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[b]
				Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
AISI 301	W	123	5,640	113	+8	–	0	57	+5	NADC (7)
AISI 301	S	123	5,640	175	+1	125	+7	27	+19	CEL (4)
AISI 301	W	403	6,780	175	0	125	0	27	-4	CEL (4)
AISI 301	S	403	6,780	175	+1	125	+1	27	-5	CEL (4)
AISI 301	W	751	5,640	175	-17	125	-16	27	-19	CEL (4)
AISI 301	S	751	5,640	175	-1	125	0	27	-3	CEL (4)
AISI 301	W	1,064	5,300	175	-3	125	-2	27	-10	CEL (4)
AISI 301	S	1,064	5,300	175	+1	125	+9	27	-16	CEL (4)
AISI 301	W	197	2,340	175	-1	125	-7	27	-16	CEL (4)
AISI 301	S	197	2,340	175	+1	125	-8	27	-4	CEL (4)
AISI 301	W	402	2,370	175	+1	125	-2	27	-5	CEL (4)
AISI 301	S	402	2,370	175	+3	125	-3	27	0	CEL (4)
AISI 301	W	181	5	175	-5	125	-1	27	-10	CEL (4)
AISI 301	W	365	5	175	-5	125	-2	27	+10	CEL (4)
AISI 302	S	123	5,640	93	+4	44	-4	54	+4	CEL (4)
AISI 302	W	403	6,780	93	+2	44	0	54	-3	CEL (4)
AISI 302	S	403	6,780	93	+4	44	+1	54	-3	CEL (4)
AISI 302	W	751	5,640	93	+3	44	+1	54	-3	CEL (4)
AISI 302	S	751	5,640	93	+3	44	-2	54	-2	CEL (4)
AISI 302	W	197	2,340	93	-3	44	-10	54	-3	CEL (4)
AISI 302	S	197	2,340	93	-4	44	-10	54	-2	CEL (4)
AISI 302	W	402	2,370	93	+1	44	0	54	-5	CEL (4)
AISI 302	S	402	2,370	93	+1	44	+1	54	-7	CEL (4)
AISI 302	W	181	5	93	0	44	-5	54	-11	CEL (4)
AISI 302	S	365	5	93	+4	44	+2	54	+3	CEL (4)
AISI 304	W	123	5,640	86	+2	36	+1	60	+8	CEL (4)
AISI 304	W	403	6,780	86	+1	36	+6	60	-8	CEL (4)
AISI 304	S	403	6,780	86	+1	36	+5	60	-3	CEL (4)
AISI 304	W	751	5,640	86	-1	36	+6	60	-4	CEL (4)
AISI 304	W	1,064	5,300	86	0	36	+3	60	-5	CEL (4)
AISI 304	S	1,064	5,300	86	-1	36	+2	60	-6	CEL (4)
AISI 304	W	197	2,340	91	+8	47	+4	50	0	NADC (7)
AISI 304	W	197	2,340	86	+1	36	+7	60	-4	CEL (4)
AISI 304	S	197	2,340	86	+1	36	+4	60	-3	CEL (4)

Continued

Table 43. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[b]
				Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
AISI 304, welded	W	402	2,370	91	+3	47	–	50	+2	NADC (7)
AISI 304	W	402	2,370	86	0	36	+6	60	-5	CEL (4)
AISI 304	S	402	2,370	86	-1	36	+2	60	-5	CEL (4)
AISI 304	W	181	5	86	-1	36	+2	60	-13	CEL (4)
AISI 304L	S	123	5,640	81	+5	40	+5	56	+8	CEL (4)
AISI 304L	W	403	6,780	81	-5	40	+6	56	-29	CEL (4)
AISI 304L	S	403	6,780	81	+3	40	+6	56	-2	CEL (4)
AISI 304L	W	751	5,640	81	+3	40	+4	56	-1	CEL (4)
AISI 304L	S	751	5,640	81	+4	40	+6	56	+2	CEL (4)
AISI 304L	W	1,064	5,300	81	-32	40	-30	56	-35	CEL (4)
AISI 304L	S	1,064	5,300	81	+3	40	+8	56	-6	CEL (4)
AISI 304L	W	197	2,340	79	+3	42	-12	55	-6	NADC (7)
AISI 304L	W	197	2,340	81	+1	40	+3	56	-4	CEL (4)
AISI 304L	S	197	2,340	81	-2	40	-9	56	+2	CEL (4)
AISI 304L, welded	W	402	2,370	.	-10	42	–	–	–	NADC (7)
AISI 304L, sensitized	W	402	2,370	–	-9	–	-2	–	–	NADC (7)
AISI 304L	W	402	2,370	81	+4	40	+14	56	-4	CEL (4)
AISI 304L	S	402	2,370	81	+4	40	+8	56	-6	CEL (4)
AISI 304L	W	181	5	81	+1	40	+3	56	-7	CEL (4)
AISI 304L	W	365	5	81	-1	40	+4	56	-17	CEL (4)
AISI 316	S	123	5,640	82	0	37	0	55	0	CEL (4)
AISI 316	W	403	6,780	82	+1	37	+9	55	-5	CEL (4)
AISI 316	S	403	6,780	82	+1	37	+10	55	-7	CEL (4)
AISI 316	W	751	5,640	82	+1	37	+10	55	-4	CEL (4)
AISI 316	S	751	5,640	82	+2	37	+12	55	-6	CEL (4)
AISI 316	W	1,064	5,300	82	+2	37	+9	55	-5	CEL (4)
AISI 316	W	1,064	5,300	81	+1	48	-9	52	-5	CEL (4)
AISI 316	S	1,064	5,300	82	+2	37	+7	55	-7	CEL (4)
AISI 316	S	1,064	5,300	81	+1	48	-11	52	0	CEL (4)
AISI 316	W	197	2,340	84	+1	47	+4	46	0	NADC (7)
AISI 316	W	197	2,340	82	0	37	+13	55	-4	CEL (4)
AISI 316	S	197	2,340	82	+3	37	+9	55	-2	CEL (4)
AISI 316, sensitized[c]	W	402	2,370	84	-44	47	-47	46	+9	NADC (7)
AISI 316	W	402	2,370	82	+2	37	+7	55	-6	CEL (4)
AISI 316	S	402	2,370	82	+2	37	+10	55	-6	CEL (4)

Continued

Table 43. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[b]
				Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
AISI 316	W	181	5	82	+2	37	+14	55	-8	CEL (4)
AISI 316	W	365	5	82	+1	37	+9	55	+1	CEL (4)
AISI 316L	S	123	5,640	86	-1	48	-2	48	+2	CEL (4)
AISI 316L	W	403	6,780	86	+1	48	0	48	-1	CEL (4)
AISI 316L	S	403	6,780	86	+1	48	+5	48	-1	CEL (4)
AISI 316L	W	751	5,640	86	+1	48	+1	48	+3	CEL (4)
AISI 316L	S	751	5,640	86	0	48	0	48	0	CEL (4)
AISI 316L	W	197	2,340	86	+1	48	-3	48	+2	CEL (4)
AISI 316L	S	197	2,340	86	+1	48	-2	48	+1	CEL (4)
AISI 316L, welded	W	402	2,370	–	-9	–	-9		–	NADC (7)
AISI 316L, sensitized	W	402	2,370	–	0	–	0	–	0	NADC (7)
AISI 316L	W	402	2,370	86	0	48	-1	48	-4	CEL (4)
AISI 316L	S	402	2,370	86	+1	48	+2	48	-4	CEL (4)
AISI 316L	W	181	5	86	0	48	-2	48	-8	CEL (4)
AISI 316L	W	365	5	86	+2	48	+3	48	+5	CEL (4)
AISI 321	W	123	5,640	83	-1	–	0	50	0	NADC (7)
AISI 321	W	1,064	5,300	83	-37	–	-61	50	+18	NADC (7)
AISI 321	W	1,064	5,300	80	+13	33	+3	53	+6	NADC (7)
AISI 321	W	197	2,340	80	+8	33	+15	53	-9	NADC (7)
AISI 347	W	123	5,640	94	0	–	0	46	+9	NADC (7)
AISI 347	W	751	5,640	94	+2	–	–	46	0	NADC (7)

[a] W = Totally exposed in seawater on sides of structure; S = Exposed in base of structure so that the lower portions of the specimen were embedded in the bottom sediments.

[b] Numbers refer to references at end of report.

[c] Welded and then sensitized.

Table 44. Chemical Compositions of 400 Series Stainless Steels, Percent by Weight

Alloy	C	Mn	P	S	Si	Ni	Cr	Mo	Al	Other	Fe[a]	Source[b]
AISI 405	0.06	0.41	0.025	0.019	0.56	–	12.6	–	0.26	–	R	CEL (4)
AISI 405	0.05	0.85	0.017	0.015	0.57	–	12.46	–	0.21	–	R	CEL (4)
AISI 405	0.05	0.62	0.014	0.011	0.27	–	14.5	–	0.27	–	R	CEL (4)
AISI 410	0.13	0.43	0.019	0.005	0.45	0.010	12.30	–	–	–	R	CEL (4)
AISI 410	0.13	0.4	–	–	–	0.2	12.1	–	–	–	R	INCO (3)
AISI 410	0.15	0.30	–	–	–	–	12.10	0.03	–	<0.09 V	R	NADC (7)
AISI 430	0.07	0.47	0.029	0.011	0.36	–	16.4	–	–	–	R	CEL (4)
AISI 430	0.05	0.46	0.012	0.010	0.36	0.12	16.5	–	–	–	R	CEL (4)
AISI 430	0.06	0.4	–	–	–	–	17.7	–	–	–	R	INCO (3)
AISI 430	0.06	0.40	–	0.013	–	<0.25	15.00	–	–	<0.20 V	R	NADC (7)
AISI 446	0.15	0.8	–	–	–	0.2	30.0	–	–	–	R	INCO (3)

[a] R = remainder.

[b] Numbers refer to references at end of report.

Table 45. Corrosion Rates and Types of Corrosion of 400 Series Stainless Steels

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Maximum Tunnel Length (mils)	Type[b]	
AISI 405	W	123	5,640	2.4	0	0		E; T	CEL (4)
AISI 405	S	123	5,640	2.0	0	0	.	E; T	CEL (4)
AISI 405	W	403	6,780	3.9	0	0	2,000	E; T	CEL (4)
AISI 405	S	403	6,780	2.4	0	0	2,500	E; T	CEL (4)
AISI 405	W	751	5,640	2.8	262	0	500	E; P (PR); T	CEL (4)
AISI 405	W	1,064	5,300	1.5	262	262	12,000	C (PR); P (PR); T	CEL (4)
AISI 405	S	1,064	5,300	1.1	262	262	6,250	C (PR); P (PR); T	CEL (4)
AISI 405	W	197	2,340	2.1	0	0	125	E; T	CEL (4)
AISI 405	S	197	2,340	1.4	0	0	380	E; T	CEL (4)
AISI 405	W	402	2,370	1.8	40	15	0	C; P	CEL (4)
AISI 405	S	402	2,370	2.0	52	11	0	C; P	CEL (4)
AISI 405	W	588	5	4.5	124	250	0	C (PR); P	CEL (4)
AISI 410	W	123	5,640	0.2	40	SL	2,950	SL-C; P (PR); T	CEL (4)
AISI 410	W	123	5,640	3.1	50	0	–	P (PR)	INCO (3)
AISI 410	W	123	5,640	<0.1	–	SL	–	SL-C	NADC (7)
AISI 410	S	123	5,640	0.3	40	SL	1,600	SL-C; P (PR); T	CEL (4)
AISI 410	S	123	5,640	2.3	50	0	–	C (PR)	INCO (3)
AISI 410	W	403	6,780	0.2	40	40	6,000	C (PR); P (PR); T	CEL (4)
AISI 410	W	403	6,780	1.9	50	50	–	C (PR); P (PR)	INCO (3)
AISI 410	W	403	6,780		–	S	EX	S-C; EX-T	NADC (7)
AISI 410	S	403	6,780	1.0	40	40	8,850	C (PR); P (PR); T	CEL (4)
AISI 410	S	403	6,780	<0.1	0	6		C	INCO (3)
AISI 410	W	751	5,640	0.5	40	40	10,000	C (PR); P (PR); T	CEL (4)
AISI 410	W	751	5,640	4.4	50	50	–	C (PR); P (PR)	INCO (3)
AISI 410	W	751	5,640	–		S	EX	S-C; EX-T	NADC (7)
AISI 410	S	751	5,640	0.4	40	40	12,000	C (PR); P (PR); T	CEL (4)
AISI 410	W	1,064	5,300	1.7	50	50	–	C (PR); P (PR)	INCO (3)
AISI 410	S	1,064	5,300	0.9	50	50	–	C (PR); P (PR)	INCO (3)
AISI 410	W	197	2,340	0.3	0	10	7,000	C; T	CEL (4)
AISI 410	W	197	2,340	1.3	50	0	–	C (PR)	INCO (3)
AISI 410	W	197	2,340	–	–	S	3,500	S-C; T	NADC (7)
AISI 410	S	197	2,340	0.2	0	15	7,000	C; E; T	CEL (4)
AISI 410	S	197	2,340	0.2	0	18	–	C	INCO (3)
AISI 410	W	402	2,370	0.5	40	40	6,400	C (PR); P (PR); T	CEL (4)

Continued

Table 45. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Maximum Tunnel Length (mils)	Type[b]	
AISI 410	W	402	2,370	0.8	50	50	–	C (PR); P (PR)	INCO (3)
AISI 410	W	402	2,370	–	–	S	EX	S-C; EX-T	NADC (7)
AISI 410	W	402	2,370	1.2	–	I	1,500	I-C; P; T	Shell (9)
AISI 410	S	402	2,370	0.4	40	40	12,000	C (PR); P (PR); T	CEL (4)
AISI 410	S	402	2,370	0.2	0	50	–	C (PR)	INCO (3)
AISI 410	S	402	2,370	2.5	1	35	1,500	C; P; T	Shell (9)
AISI 410	W	181	5	2.1	40	40	1,000	C (PR); E; P (PR); T	CEL (4)
AISI 410	W	181	5	3.4	50	50	–	C (PR); P (PR)	INCO (3)
AISI 410	W	366	5	3.0	50	50	--	C (PR); P (PR)	INCO (3)
AISI 430	W	123	5,640	0.5	0	10	1,000	C; T	CEL (4)
AISI 430	W	123	5,640	<0.1	0	I	–	I-C	INCO (3)
AISI 430	S	123	5,640	0.1	0	10	2,000	C; T	CEL (4)
AISI 430	S	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 430	W	403	6,780	0.2	137	30	3,750	C; P (PR); T	CEL (4)
AISI 430	W	403	6,780	<0.1	0	I	–	I-C	INCO (3)
AISI 430	W	403	6,780	–	–	S		S-C; S-T	NADC (7)
AISI 430	S	403	6,780	0.3	137	34	4,500	C; P (PR); T	CEL (4)
AISI 430	S	403	6,780	<0.1	0	I	–	I-C	INCO (3)
AISI 430	W	751	5,640	0.6	137	30	5,000	C; P (PR); T	CEL (4)
AISI 430	W	751	5,640	0.2	0	23	–	C	INCO (3)
AISI 430	S	751	5,640	0.1	50	50	9,000	C (PR); P (PR); T	CEL (4)
AISI 430	S	751	5,640	<0.1	0	50	–	C (PR)	INCO (3)
AISI 430	W	1,064	5,300	0.8	137	97	7,200	C; E; P (PR); T	CEL (4)
AISI 430	W	1,064	5,300	<0.1	0	I	–	I-C	INCO (3)
AISI 430	S	1,064	5,300	0.7	0	40	6,500	C; T	CEL (4)
AISI 430	S	1,064	5,300	0.2	30	30	–	C (PR); P (PR)	INCO (3)
AISI 430	W	197	2,340	0.5	0	17	2,375	C; T	CEL (4)
AISI 430	W	197	2,340	0.4	30	30	–	C (PR); P (PR)	INCO (3)
AISI 430	W	197	2,340	–	–	PR	PR	C (PR); T (PR)	NADC (7)
AISI 430	S	197	2,340	0.3	0	19	2,000	C; T	CEL (4)
AISI 430	S	197	2,340	<0.1	0	3	–	C	INCO (3)
AISI 430	W	402	2,370	0.6	137	20	6,000	C; E; P (PR); T	CEL (4)
AISI 430	W	402	2,370	0.8	30	30	–	C (PR); P (PR)	INCO (3)
AISI 430	W	402	2,370	–	–	S	S	S-C; S-T	NADC (7)

Continued

Table 45. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Maximum Tunnel Length (mils)	Type[b]	
AISI 430	S	402	2,370	0.4	137	0	11,500	E; P (PR); T	CEL (4)
AISI 430	S	402	2,370	0.2	0	8	–	C	INCO (3)
AISI 430	W	181	5	1.7	50	50	–	C (PR); P (PR)	INCO (3)
AISI 430	W	366	5	1.1	50	50	–	C (PR); P (PR)	INCO (3)
AISI 430	W	540	5	0.7	50	50	4,450	C (PR); P (PR); T	CEL (4)
AISI 430	W	588	5	0.9	50	50	3,900	C (PR); P (PR); T	CEL (4)
AISI 446	W	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 446	S	123	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 446	W	403	6,780	<0.1	0	0	–	NC	INCO (3)
AISI 446	S	403	6,780	<0.1	0	I	–	I-C	INCO (3)
AISI 446	W	751	5,640	<0.1	0	0	–	SL-ET	INCO (3)
AISI 446	S	751	5,640	<0.1	0	0	–	NC	INCO (3)
AISI 446	W	1,064	5,300	<0.1	0	0	–	NC	INCO (3)
AISI 446	S	1,064	5,300	<0.1	0	I	–	I-C	INCO (3)
AISI 446	W	197	2,340	<0.1	0	I	–	I-C	INCO (3)
AISI 446	S	197	2,340	<0.1	0	2	–	C	INCO (3)
AISI 446	W	402	2,370	<0.1	0	I	–	I-C	INCO (3)
AISI 446	S	402	2,370	<0.1	0	2	–	C	INCO (3)
AISI 446	W	181	5	0.3	50	50	–	C (PR); P (PR)	INCO (3)
AISI 446	W	366	5	0.6	50	50	–	C (PR); P (PR)	INCO (3)

[a]W = Totally exposed in seawater on sides of structure; S= Exposed in base of structure so that the lower portions of the specimen were embedded in the bottom sediments.

[b]Symbols for types of corrosion:

C	= Crevice	P	= Pitting
E	= Edge	PR	= Perforated
ET	= Etched	S	= Severe
EX	= Extensive	SL	= Slight
I	= Incipient	T	= Tunnel
NC	= No visible corrosion		

[c]Numbers refer to references at end of report.

Table 46. Stress Corrosion of 400 Series Stainless Steels

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed	Source[a]
AISI 405	43	75	403	6,780	3	0	CEL (4)
AISI 405	20	35	197	2,340	3	0	CEL (4)
AISI 405	29	50	197	2,340	3	0	CEL (4)
AISI 405	43	75	197	2,340	3	0	CEL (4)
AISI 405	43	75	402	2,340	3	0	CEL (4)
AISI 410	47	30	403	6,780	3	0	NADC (7)
AISI 410	116	75	403	6,780	3	0	NADC (7)
AISI 410	47	30	197	2,340	3	0	NADC (7)
AISI 410	116	75	197	2,340	3	0	NADC (7)
AISI 410	47	30	402	2,370	3	0	NADC (7)
AISI 410	24	50	402	2,370	3	0	CEL (4)
AISI 410	116	75	402	2,370	3	0	NADC (7)
AISI 410	36	75	402	2,370	3	0	CEL (4)
AISI 410	120	–	402	2,370	3	0	NADC (7)
AISI 430	–	30	403	6,780	3	0	NADC (7)
AISI 430	–	75	403	6,780	3	0	NADC (7)
AISI 430	–	30	197	2,340	3	0	NADC (7)
AISI 430	–	75	197	2,340	3	0	NADC (7)
AISI 430	–	30	402	2,370	3	0	NADC (7)
AISI 430	27	50	402	2,370	3	0	CEL (4)
AISI 430	–	75	402	2,370	3	0	NADC (7)
AISI 430	41	75	402	2,370	3	0	CEL (4)

[a]Numbers refer to references at end of report.

Table 47. Changes in Mechanical Properties of 400 Series Stainless Steels Due to Corrosion

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[b]
				Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
AISI 405	S	123	5,640	77	+1	59	−2	25	+3	CEL (4)
AISI 405	W	403	6,780	77	−33	59	−25	25	−61	CEL (4)
AISI 405	S	403	6,780	77	+2	59	−2	25	−7	CEL (4)
AISI 405	W	751	5,640	77	0	59	−3	25	−13	CEL (4)
AISI 405	W	197	2,340	77	+2	59	−1	25	−1	CEL (4)
AISI 405	S	197	2,340	77	+2	59	−2	25	−2	CEL (4)
AISI 405	W	402	2,370	77	−21	59	−9	25	−39	CEL (4)
AISI 405	S	402	2,370	77	+3	59	−1	25	−3	CEL (4)
AISI 410	W	123	5,640	183	−52	155	0	15	0	NADC (7)
AISI 410	S	123	5,640	80	0	49	−3	31	+8	CEL (4)
AISI 410	W	403	6,780	80	+2	49	+2	31	−8	CEL (4)
AISI 410	S	403	6,780	80	+2	49	−2	31	−4	CEL (4)
AISI 410	W	751	5,640	80	+4	49	−4	31	−8	CEL (4)
AISI 410	S	751	5,640	80	+2	49	−5	31	−3	CEL (4)
AISI 410	W	197	2,340	201	−26	155	+8	9	−11	NADC (7)
AISI 410	W	197	2,340	80	+1	49	−4	31	−3	CEL (4)
AISI 410	S	197	2,340	80	+1	49	−3	31	−3	CEL (4)
AISI 410	W	402	2,370	201	0	155	—	9	+3	NADC (7)
AISI 410	W	402	2,370	80	+1	49	−2	31	−9	CEL (4)
AISI 410	S	402	2,370	80	+1	49	−2	31	−7	CEL (4)
AISI 410	W	181	5	80	+2	49	−9	31	−13	CEL (4)
AISI 430	W	123	5,640	72	+5	54	−4	29	−6	CEL (4)
AISI 430	W	123	5,640	73	−1	55	−2	28	−1	CEL (4)
AISI 430	W	403	6,780	72	+12	54	+6	29	−22	CEL (4)
AISI 430	S	403	6,780	72	+9	54	0	29	−6	CEL (4)
AISI 430	W	751	5,640	72	−75	54	−100	29	−100	CEL (4)
AISI 430	W	1,064	5,300	72	+10	54	+4	29	−16	CEL (4)
AISI 430	S	1,064	5,300	72	−4	54	0	29	−42	CEL (4)
AISI 430	W	197	2,340	72	+4	54	+1	29	−8	CEL (4)
AISI 430	S	197	2,340	72	+6	54	+3	29	−15	CEL (4)
AISI 430	W	197	2,340	73	+3	55	+3	28	−10	CEL (4)
AISI 430	S	197	2,340	73	+3	55	0	28	−9	CEL (4)
AISI 430	W	402	2,370	72	+5	54	+5	29	−18	CEL (4)
AISI 430	W	402	2,370	73	+3	55	+2	28	−20	CEL (4)
AISI 430	S	402	2,370	73	+3	55	+1	28	−18	CEL (4)

[a]W = Totally exposed in seawater on sides of structure; S = Exposed in base of structure so that the lower portions of the specimen were embedded in the bottom sediment.

[b]Numbers refer to references at end of report.

Table 48. Chemical Compositions of Precipitation-Hardening Stainless Steels, Percent by Weight

Alloy	C	Mn	P	S	Si	Ni	Cr	Mo	Al	Cu	Other	Fe[a]	Source[b]
AISI 630	0.03	0.24	0.017	0.011	0.59	4.17	15.92	–	–	3.23	0.24 Cb	R	CEL (4)
AISI 630	–	1.00	–	–	–	4.00	17.30	–	–	3.00	<0.04 V	R	NADC (7)
AISI 631	0.07	0.48	0.017	0.018	0.42	7.42	17.12	–	1.19	–	–	R	CEL (4)
AISI 631	–	0.69	–	–	–	7.70	17.40	0.30	–	–	–	R	NADC (7)
AISI 632	0.07	0.50	0.016	0.016	0.28	7.19	15.05	2.19	1.11	–	–	R	CEL (4)
AISI 632[c]													NADC (7)
AISI 633	–	–	–	–	–	4.0	17.0	3.0	–	–	–	R	INCO (3)
AISI 633	–	–	–	–	–	4.0	14.0	3.0	–	–	–	R	MEL (5)
AISI 634	0.12	0.77	0.021	0.009	0.34	6.42	15.35	2.73	–	–	0.095 N	R	CEL (4)
AISI 635	0.05	0.54	0.011	0.006	0.57	6.89	16.8	–	0.14	–	0.64 Ti	R	CEL (4)
AISI 635	0.05	0.56	0.026	0.009	0.74	6.80	16.8	–	0.09	–	0.79 Ti	R	CEL (4)
AISI XM16	0.03	0.50	–	–	0.50	8.50	12.00	–	–	1.50	1.15 Ti 0.50 Cb + Ta	R	CEL (4)
PH14-8 Mo	0.04	0.36	0.004	0.002	0.34	8.12	14.71	2.25	1.21	–	–	R	CEL (4)
15-7 AMV	0.27	0.67	0.020	0.012	0.84	7.4	15.0	2.42	1.55	–	0.16 V	R	CEL (4)
AL362	0.03	0.30	0.015	0.015	0.20	6.50	14.50	–	–	–	0.80 Ti	R	CEL (4)
17Cr-14Ni-Cu-Mo	–	–	–	–	–	14.0	16.0	2.0	–	3.0	–	R	INCO (3)
18Cr-14Mn-0.5N	0.07	14.3	0.021	0.03	0.67	0.27	18.4	–	–	–	0.48 N	R	CEL (4)
18Cr-14Mn-0.5N	–	15.0	–	–	–	0.5	18.0	–	–	–	0.5 N	R	INCO (3)

[a] R = remainder.

[b] Numbers refer to references at end of report.

[c] No values given.

Table 49. Corrosion Rates and Types of Corrosion of Precipitation-Hardening Stainless Steels

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion						Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Maximum Tunnel Length (mils)	Type[b]	Weld[b]	
AISI 630, A	W	197	2,340	0.4	–	–	–	NU	–	Boeing (6)
AISI 630, H925[d]	W	403	6,780	<0.1	0	0	0	NC	NC	CEL (4)
AISI 630, H925[e]	W	403	6,780	<0.1	0	0	0	NC	T; WB (PR)	CEL (4)
AISI 630, H925[d]	S	403	6,780	0.4	0	0	4,500	T	T; WB (PR)	CEL (4)
AISI 630, H925[e]	S	403	6,780	<0.1	0	0	1,000	T	T; HAZ (PR)	CEL (4)
AISI 630, H925[d]	W	197	2,340	0.1	0	0	0	NC	NC	CEL (4)
AISI 630, H925[e]	W	197	2,340	<0.1	0	0	0	NC	NC	CEL (4)
AISI 630, H925[d]	S	197	2,340	0.2	0	0	0	NC	WB (U)	CEL (4)
AISI 630, H925[e]	S	197	2,340	0.2	0	0	1,200	T	NC	CEL (4)
AISI 630, H925[d]	W	402	2,370	<0.1	0	0	0	NC	NC	CEL (4)
AISI 630, H925[e]	W	402	2,370	<0.1	0	0	0	NC	NC	CEL (4)
AISI 630, H925[d]	S	402	2,370	0.6	112	0	1,750	E; P (PR); T	NC	CEL (4)
AISI 630, H925[e]	S	402	2,370	<0.1	0	0	0	NC	NC	CEL (4)
AISI 630, H925[d]	W	181	5	3.0	112	112	1,800	C (PR); E; P (PR); T	NC	CEL (4)
AISI 630, H925[e]	W	181	5	3.2	112	112	1,000	C (PR); E; P (PR); T	NC	CEL (4)
AISI 630, H925[e]	W	398	5	1.4	112	112	0	C (PR); E; P (PR)	T; WB&HAZ (PR)	CEL (4)
AISI 631, A	W	123	5,640	–	–	–	–	SC-P	–	NADC (7)
AISI 631, TH1050[d]	W	403	6,780	0.2	0	0	1,750	E; T	NC	CEL (4)
AISI 631, TH1050[e]	W	403	6,780	1.1	125	0	1,000	E; P (PR); T	T; WB (PR)	CEL (4)
AISI 631, TH1050[d]	S	403	6,780	0.6	125	0	1,500	P (PR); T	SCC	CEL (4)
AISI 631, TH1050[e]	S	403	6,780	1.6	0	125	4,000	C (PR); S-E; T	NC	CEL (4)
AISI 631, TH1050[d]	W	197	2,340	0.4	125	125	1,250	C (PR); P (PR); T	NC	CEL (4)
AISI 631, TH1050[e]	W	197	2,340	0.1	125	125	750	C (PR); P (PR); T	NC	CEL (4)
AISI 631, A	W	197	2,340	–	–	S	S	S-C; S-T	–	NADC (7)
AISI 631, TH1050[d]	S	197	2,340	0.3	125	125	1,500	C (PR); P (PR); T	NC	CEL (4)
AISI 631, TH1050[e]	S	197	2,340	<0.1	125	125	375	C (PR); P (PR); T	NC	CEL (4)
AISI 631, TH1050[d]	W	402	2,370	0.4	125	0	3,750	E; P (PR); T	I-P	CEL (4)
AISI 631, TH1050[e]	W	402	2,370	0.6	125	0	3,250	E; P (PR); T	I-P	CEL (4)
AISI 631, TH1050[d]	S	402	2,370	0.6	125	0	3,500	E; P (PR); T	I-P	CEL (4)
AISI 631, TH1050[e]	S	402	2,370	0.5	125	0	4,250	E; P (PR); T	I-P	CEL (4)
AISI 631, TH1050[d]	W	181	5	4.4	125	125	4,000	C (PR); E; P (PR); T	NC	CEL (4)
AISI 631, TH1050[e]	W	181	5	2.7	125	125	1,000	C (PR); E; P (PR); T	WB&HAZ (PR)	CEL (4)
AISI 631, TH1050[d]	W	398	5	1.9	125	125	2,600	C (PR); P (PR); T	SCC	CEL (4)

Continued

Table 49. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion						Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Maximum Tunnel Length (mils)	Type[b]	Weld[b]	
AISI 631, RH1050[d]	W	403	6,780	0.4	125	125	3,000	C (PR); P (PR); T	SCC	CEL (4)
AISI 631, RH1050[e]	W	403	6,780	1.0	I	125	2,000	C (PR); I-P; T	I-P	CEL (4)
AISI 631, RH1050[d]	S	403	6,780	1.3	I	125	6,000	C (PR); S-E; I-P; T; X	I-P	CEL (4)
AISI 631, RH1050[e]	S	403	6,780	0.8	125	0	1,500	P (PR); T; X	I-P	CEL (4)
AISI 631, RH1050[d]	W	197	2,340	0.3	I	0	1,375	I-P; T; SCC	SCC	CEL (4)
AISI 631, RH1050[e]	W	197	2,340	0.6	125	0	1,500	P (PR); T	T; HAZ (PR)	CEL (4)
AISI 631, RH1050[d]	S	197	2,340	0.6	0	125	1,000	C (PR); T	NC	CEL (4)
AISI 631, RH1050[e]	S	197	2,340	0.3	125	0	1,250	P (PR); T	NC	CEL (4)
AISI 631, RH1050[d]	W	402	2,370	<0.1	I	0	1,250	I-P; T	I-P	CEL (4)
AISI 631, RH1050[e]	W	402	2,370	0.7	125	0	2,500	P (PR); T	I-P	CEL (4)
AISI 631, RH1050[d]	S	402	2,370	<0.1	125	0	3,000	P (PR); T	SCC	CEL (4)
AISI 631, RH1050[e]	S	402	2,370	0.5	125	0	5,800	P (PR); T	T; HAZ (PR)	CEL (4)
AISI 631, RH1050[d]	W	181	5	2.9	125	125	2,500	C (PR); S-E; P (PR); T	NC	CEL (4)
AISI 631, RH1050[e]	W	181	5	3.3	125	125	1,000	C (PR); S-E; P (PR); T	NC	CEL (4)
AISI 632, RH1100[d]	W	403	6,780	2.1	125	125	2,850	C (PR); P (PR); T	NC	CEL (4)
AISI 632, RH1100[e]	W	403	6,780	1.5	125	125	2,000	C (PR); P (PR); T	NC	CEL (4)
AISI 632, RH1100[d]	S	403	6,780	1.1	125	125	2,100	C (PR); P (PR); T	NC	CEL (4)
AISI 632, RH1100[e]	S	403	6,780	1.2	125	125	5,500	C (PR); P (PR); T	NC	CEL (4)
AISI 632, RH1100[d]	W	197	2,340	0.6	125	96	750	C; P (PR); T	NC	CEL (4)
AISI 632, RH1100[e]	W	197	2,340	0.2	125	0	500	E; P (PR); T	NC	CEL (4)
AISI 632, RH1100[d]	S	197	2,340	0.5	125	0	750	E; P (PR); T	NC	CEL (4)
AISI 632, RH1100[e]	S	197	2,340	0.3	125	0	650	E; P (PR); T	NC	CEL (4)
AISI 632, RH1100[d]	W	402	2,370	0.9	125	0	1,400	P (PR); T	I-P	CEL (4)
AISI 632, RH1100[e]	W	402	2,370	0.7	125	0	1,000	P (PR); T	NC	CEL (4)
AISI 632, RH1100[d]	S	402	2,370	0.7	I	0	1,000	I-P; T	SCC	CEL (4)
AISI 632, RH1100[e]	S	402	2,370	0.6	125	0	1,000	P (PR); T	I-P; HAZ (T)	CEL (4)
AISI 632, RH1100[d]	W	181	5	3.7	125	0	1,150	S-E; P (PR); T	NC	CEL (4)
AISI 632, RH1100[e]	W	181	5	3.7	125	0	1,000	S-E; P (PR); T	NC	CEL (4)
AISI 632, RH1100[e]	W	398	5	1.8	125	125	750	C (PR); P (PR); T	NC	CEL (4)
AISI 633	W	123	5,640	<0.1	0	0	–	NC	–	INCO (3)
AISI 633	W	123	5,640	1.4	0	43	–	C	–	MEL (5)
AISI 633	S	123	5,640	<0.1	0	0	–	NC	–	INCO (3)
AISI 633	W	403	6,780	<0.1	0	I	–	I-C	–	INCO (3)

Continued

Table 49. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion: Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Maximum Tunnel Length (mils)	Type[b]	Weld[b]	Source[c]
AISI 633	S	403	6,780	<0.1	0	0	–	NC	–	INCO (3)
AISI 633	W	751	5,640	<0.1	0	0	–	NC	–	INCO (3)
AISI 633	W	751	5,640	6.3	0	63	–	C (PR)	–	MEL (5)
AISI 633	S	751	5,640	<0.1	0	I	–	I-C	–	INCO (3)
AISI 633	W	1,064	5,300	<0.1	0	0	–	NC	–	INCO (3)
AISI 633	W	1,064	5,300	2.8	0	63	–	C (PR)	–	MEL (5)
AISI 633	S	1,064	5,300	<0.1	0	1	–	C	–	INCO (3)
AISI 633	W	197	2,340	<0.1	0	I	–	I-C	–	INCO (3)
AISI 633	S	197	2,340	<0.1	0	I	–	I-C	–	INCO (3)
AISI 633	W	402	2,370	<0.1	0	I	–	I-C	–	INCO (3)
AISI 633	S	402	2,370	<0.1	0	I	–	I-C	–	INCO (3)
AISI 633	W	181	5	<0.1	0	I	–	I-C	–	INCO (3)
AISI 633	W	366	5	<0.1	0	I	–	I-C	–	INCO (3)
AISI 634, CRT	W	123	5,640	<0.1	0	0	0	NC	–	CEL (4)
AISI 634, CRT	W	403	6,780	0.2	0	50	0	C	–	CEL (4)
AISI 634, CRT	S	403	6,780	<0.1	0	30	0	C	–	CEL (4)
AISI 634, CRT	W	751	5,640	0.0	0	0	0	NC	–	CEL (4)
AISI 634, CRT	W	197	2,340	0.2	I	I	0	I-C; I-P	–	CEL (4)
AISI 634, CRT	S	197	2,340	<0.1	I	0	0	I-P	–	CEL (4)
AISI 634, CRT	W	402	2,370	0.4	I	38	0	C; I-P	–	CEL (4)
AISI 634, CRT	S	402	2,370	0.1	I	20	0	C; I-P	–	CEL (4)
AISI 635	W	123	5,640	<0.1	0	SL	0	SL-C	–	CEL (4)
AISI 635	S	123	5,640	<0.1	0	0	0	NC	–	CEL (4)
AISI 635	W	403	6,780	0.2	0	20	0	C	–	CEL (4)
AISI 635	S	403	6,780	0.1	0	11	0	C	–	CEL (4)
AISI 635	W	751	5,640	<0.1	0	0	0	NC	–	CEL (4)
AISI 635	W	1,064	5,300	<0.1	0	50	0	C	–	CEL (4)
AISI 635	S	1,064	5,300	<0.1	0	0	0	NC	–	CEL (4)
AISI 635	W	197	2,340	<0.1	0	0	0	NC	–	CEL (4)
AISI 635	S	197	2,340	<0.1	0	0	0	NC	–	CEL (4)
AISI 635	W	402	2,370	0.3	0	275	0	C (PR)	–	CEL (4)
AISI 635	S	402	2,370	<0.1	0	0	0	NC	–	CEL (4)
AISI 635	W	181	5	0.9	40	275	1,000	C (PR); E; P; T	–	CEL (4)

Continued[d]

Table 49. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion: Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Maximum Tunnel Length (mils)	Type[b]	Weld[b]	Source[c]
AISI 635	W	398	5	0.6	40	40	1,200	C; E; P; T	–	CEL (4)
ASTM XM16, H950	W	189	5,900	–	–	–	–	I-C; SPP	–	CEL (4)
ASTM XM16, H950[d]	W	189	5,900	–	–	–	–	I-C; SPP	SC-P	CEL (4)
ASTM XM16, H1050	W	189	5,900	–	–	–	–	I-C; SPP	–	CEL (4)
ASTM XM16, H1050[d]	W	189	5,900	–	–	–	–	I-C; SPP	F-P (WB)	CEL (4)
PH14-8Mo, SRH950[d]	W	403	6,780	0.4	I	0	3,000	I-P; T	I-P	CEL (4)
PH14-8Mo, SRH950[e]	W	403	6,780	<0.1	I	0	0	I-P	I-P	CEL (4)
PH14-8Mo, SRH950[d]	S	403	6,780	0.2	120	0	2,000	P (PR); T	HAZ (PR120)	CEL (4)
PH14-8Mo, SRH950[e]	S	403	6,780	<0.1	I	0	0	I-P	I-P	CEL (4)
PH14-8Mo, SRH950[d]	W	197	2,340	0.3	0	I	500	I-C; T	NC	CEL (4)
PH14-8Mo, SRH950[e]	W	197	2,340	<0.1	I	0	0	I-P	NC	CEL (4)
PH14-8Mo, SRH950[d]	S	197	2,340	<0.1	0	I	0	I-C	NC	CEL (4)
PH14-8Mo, SRH950[e]	S	197	2,340	<0.1	0	0	0	NC	NC	CEL (4)
PH14-8Mo, SRH950[d]	W	402	2,370	0.5	I	120	2,000	C (PR); I-P; T	I-P	CEL (4)
PH14-8Mo, SRH950[e]	W	402	2,370	<0.1	I	0	0	I-P	I-P	CEL (4)
PH14-8Mo, SRH950[d]	S	402	2,370	0.3	120	0	3,000	P (PR); T	I-P	CEL (4)
PH14-8Mo, SRH950[e]	S	402	2,370	<0.1	I	0	0	I-P	I-P	CEL (4)
PH14-8Mo, SRH950[d]	W	181	5	3.1	120	0	2,400	S-E; P (PR); T	NC	CEL (4)
PH14-8Mo, SRH950[e]	W	181	5	1.7	120	0	1,400	S-E; P (PR); T	WB (PR90)	CEL (4)
15-7 AMV, A	W	123	5,640	<0.1	48	48	750	C (PR); P (PR); T	–	CEL (4)
15-7 AMV, A	S	123	5,640	0.4	48	48	1,800	C (PR); P (PR); T	–	CEL (4)
15-7 AMV, A	W	403	6,780	1.2	48	48	4,000	C (PR); P (PR); T; X	–	CEL (4)
15-7 AMV, A	S	403	6,780	0.8	48	48	2,500	C (PR); P (PR); T; X	–	CEL (4)
15-7 AMV, A	W	751	5,640	2.7	48	48	6,000	C (PR); P (PR); T; X	–	CEL (4)
15-7 AMV, A	S	751	5,640	2.4	48	48	6,000	C (PR); P (PR); T; X	–	CEL (4)
15-7 AMV, A	W	1,064	5,300	3.0	48	48	0	C (PR); P (PR); X	–	CEL (4)
15-7 AMV, A	S	1,064	5,300	0.9	48	48	0	C (PR); P (PR); X	–	CEL (4)
15-7 AMV, A	W	197	2,340	0.4	48	48	2,000	C (PR); E; P (PR); T	–	CEL (4)
15-7 AMV, A	S	197	2,340	0.3	48	48	4,000	C (PR); E; P (PR); T	–	CEL (4)
15-7 AMV, A	W	402	2,370	0.5	48	48	7,300	C (PR); E; P (PR); T	–	CEL (4)
15-7 AMV, A	S	402	2,370	0.5	48	48	13,800	C (PR); E; P (PR); T; X	–	CEL (4)

Continued

Table 49. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion						Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Maximum Tunnel Length (mils)	Type[b]	Weld[b]	
15-7 AMV, RH1150	W	123	5,640	0.1	45	45	0	C (PR); P (PR)	–	CEL (4)
15-7 AMV, RH1150	S	123	5,640	0.1	45	45	1,150	C (PR); P (PR); T	–	CEL (4)
15-7 AMV, RH1150	W	403	6,780	1.2	45	45	5,750	C (PR); P (PR); T	–	CEL (4)
15-7 AMV, RH1150	S	403	6,780	1.2	45	45	4,500	C (PR); P (PR); T	–	CEL (4)
15-7 AMV, RH1150	W	751	5,640	1.5	45	45	6,000	C (PR); P (PR); T; X	–	CEL (4)
15-7 AMV, RH1150	S	751	5,640	1.2	45	45	6,000	C (PR); P (PR); T; X	–	CEL (4)
15-7 AMV, RH1150	W	1,064	5,300	1.1	45	45	5,000	C (PR); P (PR); T	–	CEL (4)
15-7 AMV, RH1150	S	1,064	5,300	0.9	45	45	6,000	C (PR); P (PR); T	–	CEL (4)
15-7 AMV, RH1150	W	197	2,340	0.4	45	45	3,300	C (PR); P (PR); T	–	CEL (4)
15-7 AMV, RH1150	S	197	2,340	0.7	45	45	1,150	C (PR); P (PR); T	–	CEL (4)
15-7 AMV, RH1150	W	402	2,370	1.0	45	45	8,750	C (PR); E; P (PR); T; X	–	CEL (4)
15-7 AMV, RH1150	S	402	2,370	0.7	45	45	4,000	C (PR); E; P (PR); T	–	CEL (4)
15-7 AMV, RH950	W	123	5,640	0.7	48	48	0	C (PR); P (PR)	–	CEL (4)
15-7 AMV, RH950	S	123	5,640	1.3	48	48	2,900	C (PR); P (PR); T; X	–	CEL (4)
15-7 AMV, RH950	W	403	6,780	1.0	48	48	3,750	C (PR); P (PR); T; X	–	CEL (4)
15-7 AMV, RH950	S	403	6,780	1.2	48	48	5,000	C (PR); P (PR); T; X	–	CEL (4)
15-7 AMV, RH950	W	751	5,640	1.6	48	48	6,000	C (PR); E; P (PR); T	–	CEL (4)
15-7 AMV, RH950	W	1,064	5,300	2.0	48	48	6,000	C (PR); P (PR); T; X	–	CEL (4)
15-7 AMV, RH950	S	1,064	5,300	0.9	48	48	6,000	C (PR); P (PR); T; X	–	CEL (4)
15-7 AMV, RH950	W	197	2,340	0.8	48	48	1,000	C (PR); E; P (PR); T	–	CEL (4)
15-7 AMV, RH950	S	197	2,340	0.7	48	48	1,750	C (PR); E; P (PR); T	–	CEL (4)
15-7 AMV, RH950	W	402	2,370	0.6	48	48	4,650	C (PR); E; P (PR); T	–	CEL (4)
15-7 AMV, RH950	S	402	2,370	0.6	48	48	6,000	C (PR); E; P (PR); T	–	CEL (4)
AL362, H950	W	189	5,900	–	–	–	–	I-C; SPP	–	CEL (4)
AL362, H950[d]	W	189	5,900	–	–	–	–	I-C; SPP	SPP (WB)	CEL (4)
AL362, H1050	W	189	5,900	–	–	–	–	I-C; SPP	–	CEL (4)
AL362, H1050[d]	W	189	5,900	–	–	–	–	S-C; SPP	D-P (WB)	CEL (4)
17Cr-14Ni-Cu-Mo	W	123	5,640	<0.1	0	0	–	NC	–	INCO (3)
17Cr-14Ni-Cu-Mo	S	123	5,640	<0.1	0	0	–	NC	–	INCO (3)
17Cr-14Ni-Cu-Mo	W	403	6,780	<0.1	0	I	–	I-C	–	INCO (3)
17Cr-14Ni-Cu-Mo	S	403	6,780	<0.1	0	I	–	I-C	–	INCO (3)
17Cr-14Ni-Cu-Mo	W	751	5,640	<0.1	0	I	–	I-C	–	INCO (3)

Continued

Table 49. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion						Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Maximum Tunnel Length (mils)	Type[b]	Weld[b]	
17Cr-14Ni-Cu-Mo	S	751	5,640	<0.1	0	I	–	I-C	–	INCO (3)
17Cr-14Ni-Cu-Mo	W	1,064	5,300	<0.1	0	I	–	I-C	–	INCO (3)
17Cr-14Ni-Cu-Mo	S	1,064	5,300	<0.1	0	3	–	C	–	INCO (3)
17Cr-14Ni-Cu-Mo	W	197	2,340	<0.1	0	I	–	I-C	–	INCO (3)
17Cr-14Ni-Cu-Mo	S	197	2,340	<0.1	0	I	–	I-C	–	INCO (3)
17Cr-14Ni-Cu-Mo	W	402	2,370	<0.1	0	I	–	I-C	–	INCO (3)
17Cr-14Ni-Cu-Mo	S	402	2,370	<0.1	0	I	–	I-C	–	INCO (3)
17Cr-14Ni-Cu-Mo	W	181	5	<0.1	3	0	–	P	–	INCO (3)
17Cr-14Ni-Cu-Mo	W	366	5	<0.1	0	I	–	I-C	–	INCO (3)
18Cr-14Mn-0.5N	W	123	5,640	<0.1	0	0	0	NC	–	CEL (4)
18Cr-14Mn-0.5N	W	123	5,640	<0.1	0	0	–	NC	–	INCO (3)
18Cr-14Mn-0.5N	S	123	5,640	0.3	0	115	0	C (PR)	–	CEL (4)
18Cr-14Mn-0.5N	S	123	5,640	<0.1	0	0	–	NC	–	INCO (3)
18Cr-14Mn-0.5N	W	403	6,780	0.5	115	0	2,750	P (PR); T	–	CEL (4)
18Cr-14Mn-0.5N	W	403	6,780	<0.1	0	I	–	I-C	–	INCO (3)
18Cr-14Mn-0.5N	S	403	6,780	0.6	115	115	2,000	C (PR); P (PR); T	–	CEL (4)
18Cr-14Mn-0.5N	S	403	6,780	<0.1	0	3	–	C	–	INCO (3)
18Cr-14Mn-0.5N	W	751	5,640	0.2	115	24	2,800	C; P (PR); T	–	CEL (4)
18Cr-14Mn-0.5N	W	751	5,640	<0.1	0	0	–	NC	–	INCO (3)
18Cr-14Mn-0.5N	S	751	5,640	<0.1	0	0	0	NC	–	CEL (4)
18Cr-14Mn-0.5N	S	751	5,640	<0.1	0	3	–	C	–	INCO (3)
18Cr-14Mn-0.5N	W	1,064	5,300	0.2	115	0	2,250	P (PR); T	–	CEL (4)
18Cr-14Mn-0.5N	W	1,064	5,300	<0.1	0	0	–	NC	–	INCO (3)
18Cr-14Mn-0.5N	S	1,064	5,300	0.3	115	0	4,000	P (PR); T	–	CEL (4)
18Cr-14Mn-0.5N	S	1,064	5,300	0.4	62	62	–	C (PR); P (PR)	–	INCO (3)
18Cr-14Mn-0.5N	W	197	2,340	0.8	115	109	1,250	C; P (PR); T	–	CEL (4)
18Cr-14Mn-0.5N	W	197	2,340	<0.1	0	I	–	I-C	–	INCO (3)
18Cr-14Mn-0.5N	S	197	2,340	0.4	115	21	1,000	C; P (PR); T	–	CEL (4)
18Cr-14Mn-0.5N	S	197	2,340	<0.1	0	13	–	C	–	INCO (3)
18Cr-14Mn-0.5N	W	402	2,370	0.8	115	0	2,000	P (PR); T	–	CEL (4)
18Cr-14Mn-0.5N	W	402	2,370	1.1	0	62	–	C (PR)	–	INCO (3)
18Cr-14Mn-0.5N	S	402	2,370	1.0	115	0	3,000	P (PR); T	–	CEL (4)
18Cr-14Mn-0.5N	S	402	2,370	<0.1	0	I	–	I-C	–	INCO (3)

Continued

Table 49. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion						Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Maximum Tunnel Length (mils)	Type[b]	Weld[b]	
18Cr-14Mn-0.5N	W	181	5	4.9	50	50	–	C (PR); P (PR)	–	INCO (3)
18Cr-14Mn-0.5N	W	366	5	2.6	50	50	–	C (PR); P (PR)	–	INCO (3)

[a]W = Totally exposed in seawater on sides of structure; S = Exposed in base of structure so that the lower portions of the specimens were embedded in the bottom sediments.

[b]Symbols for types of corrosion:

C	= Crevice	S	= Severe
D	= Deep	SC	= Scattered
E	= Edge	SCC	= Stress corrosion cracked
F	= Few	SL	= Slight
HAZ	= Heat-affected zone	SPP	= Scattered pinpoint pitting
I	= Incipient	T	= Tunnel
NC	= No visible corrosion	U	= Uniform
NU	= Nonuniform	WB	= Weld bead
P	= Pitting	X	= Portion of specimens missing due to corrosion
PR	= Perforated		

[c]Numbers refer to references at end of report.

[d]Three-inch-diameter circular weld in center of specimen.

[e]Transverse butt weld.

Table 50. Stress Corrosion of Precipitation-Hardening Stainless Steels, Calculated Stresses

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed[a]	Source[b]
AISI 630, H925[c]	65	35	403	6,780	2	0	CEL (4)
AISI 630, H925[c]	93	50	403	6,780	2	0	CEL (4)
AISI 630, H925[c]	139	75	403	6,780	2	0	CEL (4)
AISI 630, H925[c]	65	35	197	2,340	2	0	CEL (4)
AISI 630, H925[c]	93	50	197	2,340	2	0	CEL (4)
AISI 630, H925[c]	139	75	197	2,340	2	0	CEL (4)
AISI 630, H925[c]	93	50	402	2,370	3	0	CEL (4)
AISI 630, H925[c]	139	75	402	2,370	3	0	CEL (4)
AISI 630, H925[c]	65	35	70	5	3	3[d]	CEL (4)
AISI 630, H925[c]	93	50	364	5	3	1 (89)[d]	CEL (4)
AISI 630, H925[c]	139	75	364	5	3	2 (70, 233)[d]	CEL (4)
AISI 630, RH950	61	39	123	5,640	3	0	NADC (7)
AISI 630, RH950	86	55	123	5,640	3	0	NADC (7)
AISI 630, RH950	134	86	123	5,640	3	0	NADC (7)
AISI 631, TH1050[c]	66	35	403	6,780	2	0	CEL (4)
AISI 631, TH1050[c]	94	50	403	6,780	2	1	CEL (4)
AISI 631, TH1050[c]	141	75	403	6,780	2	1	CEL (4)
AISI 631, TH1050[c]	66	35	197	2,340	2	0	CEL (4)
AISI 631, TH1050[c]	94	50	197	2,340	2	0	CEL (4)
AISI 631, TH1050[c]	141	75	197	2,340	2	0	CEL (4)
AISI 631, TH1050[c]	94	50	402	2,370	3	0	CEL (4)
AISI 631, TH1050[c]	141	75	402	2,370	3	1	CEL (4)
AISI 631, TH1050[c]	66	35	364	5	3	0	CEL (4)
AISI 631, TH1050[c]	94	50	364	5	3	1 (253)[e]	CEL (4)
AISI 631, TH1050[c]	141	75	364	5	3	1 (253)[f]	CEL (4)
AISI 631, RH1050[c]	69	35	403	6,780	2	0	CEL (4)
AISI 631, RH1050[c]	98	50	403	6,780	2	0	CEL (4)
AISI 631, RH1050[c]	147	75	403	6,780	2	1[d]	CEL (4)
AISI 631, RH1050[c]	69	35	197	2,340	2	0	CEL (4)
AISI 631, RH1050[c]	98	50	197	2,340	2	0	CEL (4)
AISI 631, RH1050[c]	147	75	197	2,340	2	0	CEL (4)
AISI 631, RH1050[c]	98	50	402	2,370	3	0	CEL (4)
AISI 631, RH1050[c]	147	75	402	2,370	3	2	CEL (4)
AISI 631, RH1050[c]	69	35	364	5	3	0	CEL (4)
AISI 631, RH1050[c]	98	50	364	5	3	0	CEL (4)
AISI 631, RH1050[c]	147	75	364	5	3	1 (90)[d]	CEL (4)
AISI 632, RH1100[c]	64	35	403	6,780	2	0	CEL (4)
AISI 632, RH1100[c]	92	50	403	6,780	2	0	CEL (4)
AISI 632, RH1100[c]	138	75	403	6,780	2	0	CEL (4)
AISI 632, RH1100[c]	64	35	197	2,340	2	0	CEL (4)
AISI 632, RH1100[c]	92	50	197	2,340	2	0	CEL (4)
AISI 632, RH1100[c]	138	75	197	2,340	2	0	CEL (4)
AISI 632, RH1100[c]	92	50	402	2,370	3	0	CEL (4)
AISI 632, RH1100[c]	138	75	402	2,370	3	0	CEL (4)
AISI 632, RH1100[c]	64	35	364	5	3	0	CEL (4)
AISI 632, RH1100[c]	92	50	364	5	3	1 (322)[g]	CEL (4)
AISI 632, RH1100[c]	138	75	364	5	3	3 (56, 70, 133)[g]	CEL (4)

Continued

Table 50. Continued.

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed[a]	Source[b]
AISI 634, CRT	108	50	402	2,370	3	0	CEL (4)
AISI 634, CRT	162	75	402	2,370	3	0	CEL (4)
AISI 635	68	35	197	2,340	3	0	CEL (4)
AISI 635	97	50	197	2,340	3	0	CEL (4)
AISI 635	145	75	197	2,340	3	0	CEL (4)
AISI 635	92	50	402	2,370	3	0	CEL (4)
AISI 635	138	75	402	2,370	3	0	CEL (4)
ASTM XM16, H950	–	75	189	5,900	2	0	CEL (4)
ASTM XM16, H1050	–	75	189	5,900	1	0	CEL (4)
ASTM XM16, H1050[b]	–	75	189	5,900	1	0	CEL (4)
PH14-8Mo, SRH950[c]	75	35	403	6,780	2	0	CEL (4)
PH14-8Mo, SRH950[c]	107	50	403	6,780	2	0	CEL (4)
PH14-8Mo, SRH950[c]	161	75	403	6,780	2	1	CEL (4)
PH14-8Mo, SRH950[c]	75	35	197	2,340	2	0	CEL (4)
PH14-8Mo, SRH950[c]	107	50	197	2,340	2	0	CEL (4)
PH14-8Mo, SRH950[c]	161	75	197	2,340	2	0	CEL (4)
PH14-8Mo, SRH950[c]	107	50	402	2,370	3	1	CEL (4)
PH14-8Mo, SRH950[c]	161	75	402	2,370	3	1	CEL (4)
PH14-8Mo, SRH950[c]	75	35	364	5	3	3 (322)[d]	CEL (4)
PH14-8Mo, SRH950[c]	107	50	364	5	3	3 (322)[d]	CEL (4)
PH14-8Mo, SRH950[c]	161	75	364	5	3	0	CEL (4)
15-7 AMV, A	20	35	403	6,780	2	0	CEL (4)
15-7 AMV, A	29	50	403	6,780	2	0	CEL (4)
15-7 AMV, A	43	75	403	6,780	2	1	CEL (4)
15-7 AMV, A	20	35	197	2,340	3	0	CEL (4)
15-7 AMV, A	29	50	197	2,340	3	0	CEL (4)
15-7 AMV, A	43	75	197	2,340	3	0	CEL (4)
15-7 AMV, A	29	50	402	2,370	3	0	CEL (4)
15-7 AMV, A	43	75	402	2,370	3	0	CEL (4)
15-7 AMV, RH1150	55	35	123	5,640	3	0	CEL (4)
15-7 AMV, RH1150	79	50	123	5,640	3	0	CEL (4)
15-7 AMV, RH1150	119	75	123	5,640	3	0	CEL (4)
15-7 AMV, RH1150	55	35	403	6,780	2	0	CEL (4)
15-7 AMV, RH1150	79	50	403	6,780	2	0	CEL (4)
15-7 AMV, RH1150	119	75	403	6,780	2	0	CEL (4)
15-7 AMV, RH1150	55	35	751	5,640	3	3[i]	CEL (4)
15-7 AMV, RH1150	79	50	751	5,640	3	3[i]	CEL (4)
15-7 AMV, RH1150	119	75	751	5,640	3	3[i]	CEL (4)
15-7 AMV, RH1150	79	50	197	2,340	3	2	CEL (4)
15-7 AMV, RH1150	119	75	197	2,340	3	3	CEL (4)
15-7 AMV, RH1150	79	50	402	2,370	3	1	CEL (4)
15-7 AMV, RH1150	119	75	402	2,370	3	1	CEL (4)
15-7 AMV, RH950	77	35	123	5,640	3	1[j]	CEL (4)
15-7 AMV, RH950	110	50	123	5,640	3	3	CEL (4)
15-7 AMV, RH950	165	75	123	5,640	3	3[k]	CEL (4)
15-7 AMV, RH950	77	35	403	6,780	2	0	CEL (4)
15-7 AMV, RH950	110	50	403	6,780	2	0	CEL (4)
15-7 AMV, RH950	165	75	403	6,780	2	2	CEL (4)

Continued

Table 50. Continued.

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed[a]	Source[b]
15-7 AMV, RH950	77	35	751	5,640	3	0	CEL (4)
15-7 AMV, RH950	110	50	751	5,640	3	3	CEL (4)
15-7 AMV, RH950	165	75	751	5,640	3	3	CEL (4)
15-7 AMV, RH950	77	35	197	2,340	3	0	CEL (4)
15-7 AMV, RH950	110	50	197	2,340	3	2[j]	CEL (4)
15-7 AMV, RH950	165	75	197	2,340	3	2	CEL (4)
15-7 AMV, RH950	110	50	402	2,370	3	0	CEL (4)
15-7 AMV, RH950	165	75	402	2,370	3	3	CEL (4)
AL362, H950	-	75	189	5,900	3	0	CEL (4)
AL362, H950[h]	-	75	189	5,900	6	0	CEL (4)
AL362, H1050	-	75	189	5,900	5	0	CEL (4)
AL362, H1050[h]	-	75	189	5,900	6	0	CEL (4)
AL362, H1050[l]	-	75	189	5,900	1	0	CEL (4)
AL362, H1050[m]	-	75	189	5,900	1	0	CEL (4)
18Cr-14Mn-0.5N	41	50	402	2,370	3	0	CEL (4)
18Cr-14Mn-0.5N	61	75	402	2,370	3	0	CEL (4)

[a]Numbers in parentheses indicate days to failure.

[b]Numbers refer to references at end of report.

[c]Transverse butt weld at midlength of specimens.

[d]Failed by crevice corrosion at anvils of stress jig.

[e]Broke at edge of weld bead.

[f]Broke at junction of heat-affected zone and sheet metal.

[g]Crevice corrosion at bolt hole, released tension.

[h]Painted, zinc-rich primer, 8 mils.

[i]Specimens were missing when structure was retrieved.

[j]Incipient crack in one specimen.

[k]One specimen broke prior to exposure in the seawater.

[l]Painted, wash primer (MIL-C-8514) + red lead epoxy primer + epoxy topcoat, 7 mils.

[m]Painted, wash primer (MIL-C-8514) + epoxy primer + epoxy topcoat, 7 mils.

Table 51. Stress Corrosion of Precipitation-Hardening Stainless Steels, Residual Stresses

Alloy	Exposure (day)	Depth (ft)	Type of Residual Stress	Remarks
AISI 630, H925	403	6,780	Unrelieved circular weld	SCC[a] propagated across weld bead
AISI 631, TH1050	398	5	Unrelieved circular weld	SCC radially in three directions to circular weld bead
AISI 631, TH1050	403	6,780	Unrelieved circular weld	SCC propagated across and around weld bead
AISI 631, RH1050	197	2,340	Unrelieved circular weld	SCC, origin on outside of weld bead, propagated into heat-affected zone, circumferentially in both directions around weld
AISI 631, RH1050	402	2,370	Unrelieved circular weld	SCC, origin on outside of weld bead, propagation in both directions around weld bead at edge of heat-affected zone
AISI 631, RH1050	403	6,780	Unrelieved circular weld	SCC, origin on outside of weld bead and propagated in both directions around outside of weld bead
AISI 632, RH1100	402	2,370	Unrelieved circular weld	SCC, origin on outside edge of weld bead, propagated in both directions around weld in heat-affected zone
15-7 AMV, RH1150	123	5,640	Imposed by insulator	SCC due to squeeze by insulators on sides of panel
15-7 AMV, RH1150	1,064	5,300	Unreamed drilled hole	SCC, origin at unreamed hole, not deburred
15-7 AMV, RH950	1,064	5,300	Unreamed drilled hole	SCC, origin at unreamed hole, not deburred

[a]SCC = stress corrosion cracking failure.

Table 52. Changes in Mechanical Properties of the Precipitation-Hardening Stainless Steels Due to Corrosion

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Tensile Strength Original (ksi)	Tensile Strength % Change	Yield Strength Original (ksi)	Yield Strength % Change	Elongation Original (%)	Elongation % Change	Source[b]
AISI 630, H925[c]	W	403	6,780	192	-6	185	-6	3	-17	CEL (4)
AISI 630, H925[c]	S	403	6,780	192	-9	185	-7	3	-33	CEL (4)
AISI 630, H925[c]	W	402	2,370	192	-8	185	-11	3	-17	CEL (4)
AISI 630, H925[c]	S	402	2,370	192	-7	185	-9	3	-27	CEL (4)
AISI 630, H925[c]	W	181	5	192	-7	185	-11	3	+7	CEL (4)
AISI 630, H925[c,d]	W	365	5	192	—	185	—	3	—	CEL (4)
AISI 631, A	W	197	2,340	134	-8	58	-22	37	-3	NADC (7)
AISI 631, TH1050[c]	W	403	6,780	197	-25	188	-60	3	+77	CEL (4)
AISI 631, TH1050[c]	S	403	6,780	197	-24	188	-54	3	+57	CEL (4)
AISI 631, TH1050[c]	W	402	2,370	197	-22	188	-56	3	+40	CEL (4)
AISI 631, TH1050[c]	S	402	2,370	197	-21	188	-57	3	+57	CEL (4)
AISI 631, RH1050[c]	W	403	6,780	207	-29	197	-59	5	-7	CEL (4)
AISI 631, RH1050[c]	S	403	6,780	207	-21	197	-54	5	+9	CEL (4)
AISI 631, RH1050[c]	W	402	2,370	207	-24	197	-60	5	-7	CEL (4)
AISI 632, RH1100[c]	W	403	6,780	192	-22	183	-53	3	+33	CEL (4)
AISI 632, RH1100[c]	S	403	6,780	192	-24	183	-54	3	+43	CEL (4)
AISI 632, RH1100[c]	W	402	2,370	192	-20	183	-55	3	+43	CEL (4)
AISI 632, RH1100[c]	S	402	2,370	192	-19	183	-54	3	+5	CEL (4)
AISI 632, RH1100[c]	W	181	5	192	-15	183	-54	3	+73	CEL (4)
AISI 632, RH1100[c]	W	365	5	192	-15	183	-54	3	+72	CEL (4)
AISI 634, CRT	W	123	5,640	229	+4	215	-11	19	-1	CEL (4)
AISI 634, CRT	W	403	6,780	229	+4	215	-11	19	+2	CEL (4)
AISI 634, CRT	S	403	6,780	229	+4	215	-8	19	+4	CEL (4)
AISI 634, CRT	W	751	5,640	229	+8	215	-7	19	+4	CEL (4)
AISI 634, CRT	W	197	2,340	229	+3	215	-11	19	+4	CEL (4)
AISI 634, CRT	S	197	2,340	229	+3	215	-9	19	+4	CEL (4)
AISI 635	W	123	5,640	191	+11	184	+11	14	+7	CEL (4)
AISI 635	W	403	6,780	191	+12	184	+12	14	-32	CEL (4)
AISI 635	S	403	6,780	191	+11	184	+10	14	-33	CEL (4)
AISI 635	W	751	5,640	191	+8	184	+8	14	-26	CEL (4)
AISI 635	W	1,064	5,300	199	+2	193	+2	9	-26	CEL (4)
AISI 635	S	1,064	5,300	199	+4	193	+5	9	-24	CEL (4)
AISI 635	W	197	2,340	191	+1	184	+2	14	-18	CEL (4)

Continued

Table 52. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[b]
				Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
AISI 635	S	197	2,340	191	+2	184	+4	14	-20	CEL (4)
AISI 635	W	402	2,370	191	-2	184	-6	14	-7	CEL (4)
AISI 635	S	402	2,370	191	+7	184	+5	14	-30	CEL (4)
AISI 635	W	181	5	191	+4	184	+5	14	-38	CEL (4)
AISI 635	W	365	5	191	+1	184	+2	14	-5	CEL (4)
PH14-8Mo, SRH950[c]	W	403	6,780	229	-32	214	-53	2	+40	CEL (4)
PH14-8Mo, SRH950[c]	S	403	6,780	229	-30	214	-49	2	+150	CEL (4)
PH14-8Mo, SRH950[c]	W	402	2,370	229	-30	214	-54	2	+100	CEL (4)
PH14-8Mo, SRH950[c]	S	402	2,370	229	-32	214	-57	2	+50	CEL (4)
PH14-8Mo, SRH950[c]	W	181	5	229	-23	214	-52	2	+100	CEL (4)
15-7 AMV, A	W	123	5,640	129	-8	57	+3	27	-50	CEL (4)
15-7 AMV, A	W	403	6,780	129	+9	57	-2	27	+38	CEL (4)
15-7 AMV, A	S	403	6,780	129	+10	57	0	27	+64	CEL (4)
15-7 AMV, A	W	751	5,640	129	+6	57	+2	27	+2	CEL (4)
15-7 AMV, A	S	751	5,640	129	+4	57	+5	27	+3	CEL (4)
15-7 AMV, A	W	197	2,340	129	0	57	-10	27	+39	CEL (4)
15-7 AMV, A	S	197	2,340	129	0	57	-10	27	+43	CEL (4)
15-7 AMV, A	W	402	2,370	129	+8	57	+1	27	+34	CEL (4)
15-7 AMV, A	S	402	2,370	129	+8	57	+1	27	+44	CEL (4)
15-7 AMV, RH1150	S	123	5,640	190	-2	158	+1	8	-16	CEL (4)
15-7 AMV, RH1150	W	403	6,780	190	+4	158	+7	8	-50	CEL (4)
15-7 AMV, RH1150	S	403	6,780	190	+3	158	+9	8	-37	CEL (4)
15-7 AMV, RH1150	W	751	5,640	190	-3	158	-28	8	-31	CEL (4)
15-7 AMV, RH1150	S	751	5,640	190	+5	158	+8	8	-4	CEL (4)
15-7 AMV, RH1150	W	1,064	5,300	196	+2	166	+2	8	-10	CEL (4)
15-7 AMV, RH1150	S	1,064	5,300	196	+2	166	+3	8	-3	CEL (4)
15-7 AMV, RH1150	W	197	2,340	190	+2	158	+3	8	-1	CEL (4)
15-7 AMV, RH1150	S	197	2,340	190	+2	158	+5	8	-10	CEL (4)
15-7 AMV, RH1150	W	402	2,370	190	+5	158	+8	8	-7	CEL (4)
15-7 AMV, RH1150	S	402	2,370	190	+4	158	+4	8	-4	CEL (4)
15-7 AMV, RH950	S	123	5,640	248	-19	220	–	2	-4	CEL (4)
15-7 AMV, RH950	W	403	6,780	248	-9	220	+1	2	-100	CEL (4)
15-7 AMV, RH950	S	403	6,780	248	-2	220	+5	2	-88	CEL (4)
15-7 AMV, RH950	W	751	5,640	248	-1	220	+2	2	–	CEL (4)

Continued

Table 52. Continued

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[b]
				Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
15-7 AMV, RH950	W	197	2,340	248	-3	220	0	2	-18	CEL (4)
15-7 AMV, RH950	S	197	2,340	248	-2	220	+2	2	-18	CEL (4)
15-7 AMV, RH950	W	402	2,370	248	+2	220	+2	2	-32	CEL (4)
15-7 AMV, RH950	S	402	2,370	248	-2	220	+1	2	-18	CEL (4)
18Cr-14Mn-0.5N	S	123	5,640	126	0	81	-3	52	+6	CEL (4)
18Cr-14Mn-0.5N	W	403	6,780	126	+2	81	+6	52	-3	CEL (4)
18Cr-14Mn-0.5N	S	403	6,780	126	0	81	+2	52	-1	CEL (4)
18Cr-14Mn-0.5N	W	751	5,640	126	0	81	+5	52	-2	CEL (4)
18Cr-14Mn-0.5N	S	751	5,640	126	-1	81	+1	52	-2	CEL (4)
18Cr-14Mn-0.5N	W	1,064	5,300	126	-2	81	+4	52	-4	CEL (4)
18Cr-14Mn-0.5N	S	1,064	5,300	126	-27	81	-31	52	-36	CEL (4)
18Cr-14Mn-0.5N	W	197	2,340	126	-2	81	+5	52	-4	CEL (4)
18Cr-14Mn-0.5N	S	197	2,340	126	-1	81	+3	52	+2	CEL (4)
18Cr-14Mn-0.5N	W	402	2,370	126	+1	81	+5	52	-11	CEL (4)
18Cr-14Mn-0.5N	S	402	2,370	126	-1	81	+3	52	-9	CEL (4)

[a]W = Totally exposed in seawater on sides of structure; S = Exposed in base of structure so that the lower portions of the specimen were embedded in the bottom sediments.

[b]Numbers refer to references at end of report.

[c]Transverse butt weld at center of 12-inch length.

[d]Too badly corroded to obtain tensile specimens.

Table 53. Chemical Compositions of Miscellaneous Stainless Steels, Percent by Weight

Alloy	C	Mn	P	S	Si	Ni	Cr	Mo	Cu	Other	Fe[a]	Source[b]
20 Cb	0.04	0.79	0.018	0.004	0.67	28.38	19.80	2.06	3.11	0.77 Cb + Ta	R	CEL (4)
20 Cb	0.05	0.82	–	–	0.70	28.43	20.09	2.32	3.37	0.83 Cb + Ta	R	CEL (4)
20 Cb	–	–	–	–	–	33.0	20.0	2.5	3.5	–	R	INCO (3)
20 Cb-3[c]	0.07	2.0	0.035	0.035	1.0	34.0	20.0	2.5	3.5	Cb + Ta, 8XC	R	CEL (4)
20 Cb-3	–	–	–	–	–	34.0	20.0	2.3	3.4	–	R	INCO (3)
Ni-Cr-Cu-Mo No. 1, cast	–	–	–	–	–	30.0	20.0	2.5	4.0	–	R	INCO (3)
Ni-Cr-Cu-Mo No. 2, cast	–	–		–	–	30.0	20.0	2.5	3.5	–	R	INCO (3)
Ni-Cr-Mo, cast	–	–	–	–	–	24.0	19.0	3.0	–	–	R	INCO (3)
Ni-Cr-Mo-Si, cast	–	–	–	–	1.0	23.0	21.0	5.0	–	–	R	INCO (3)
RL-35-100, cast	–	1.0	–	–	–	31.0	23.0	9.0	–	–	R	INCO (3)

[a]R = remainder.

[b]Numbers refer to references at end of report.

[c]Typical analysis.

Table 54. Corrosion Rates and Types of Corrosion of Miscellaneous Stainless Steels

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion				Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Type[b]	
20 Cb	W	123	5,640	0	0	0	NC	CEL (4)
20 Cb	S	123	5,640	0	0	0	NC	CEL (4)
20 Cb	W	403	6,780	0	0	0	NC	CEL (4)
20 Cb	S	403	6,780	<0.1	0	102	C	CEL (4)
20 Cb	W	751	5,640	<0.1	0	26	C	CEL (4)
20 Cb	S	751	5,640	0	0	0	NC	CEL (4)
20 Cb	W	1,064	5,300	0	0	0	NC	CEL (4)
20 Cb	S	1,064	5,300	0	0	0	NC	CEL (4)
20 Cb	W	197	2,340	<0.1	0	I	I-C	CEL (4)
20 Cb	S	197	2,340	<0.1	0	I	I-C	CEL (4)
20 Cb	W	402	2,370	<0.1	0	0	NC	CEL (4)
20 Cb	S	402	2,370	<0.1	0	0	NC	CEL (4)
20 Cb	W	181	5	<0.1	0	5	C; SL-E	CEL (4)
20 Cb	W	398	5	<0.1	14	0	SL-E; P	CEL (4)
20 Cb	W	540	5	<0.1	24	0	P	CEL (4)
20 Cb	W	588	5	<0.1	0	21	C	CEL (4)
20 Cb-3	W	123	5,640	<0.1	0	0	NC	INCO (3)
20 Cb-3	S	123	5,640	<0.1	0	0	NC	INCO (3)
20 Cb-3	W	189	5,900	<0.1	I	I	I-C; I-P	CEL (4)
20 Cb-3	S	189	5,900	<0.1	0	40	C	CEL (4)

Continued

Table 54. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Corrosion Maximum Pit Depth (mils)	Corrosion Crevice Depth[b] (mils)	Corrosion Type[b]	Source[c]
20 Cb-3	W	403	6,780	<0.1	0	I	I-C	INCO (3)
20 Cb-3	S	403	6,780	<0.1	0	I	I-C	INCO (3)
20 Cb-3	W	751	5,640	<0.1	0	0	NC	INCO (3)
20 Cb-3	S	751	5,640	<0.1	0	0	NC	INCO (3)
20 Cb-3	W	1,064	5,300	<0.1	0	I	I-C	INCO (3)
20 Cb-3	S	1,064	5,300	<0.1	0	I	I-C	INCO (3)
20 Cb-3	W	197	2,340	<0.1	0	I	I-C	INCO (3)
20 Cb-3	S	197	2,340	<0.1	0	I	I-C	INCO (3)
20 Cb-3	W	402	2,370	<0.1	I	0	I-P	INCO (3)
20 Cb-3	S	402	2,370	<0.1	0	I	I-C	INCO (3)
20 Cb-3	W	181	5	<0.1	0	I	I-C	INCO (3)
20 Cb-3	W	366	5	<0.1	0	0	NC	INCO (3)
Ni-Cr-Cu-Mo No. 1, cast	W	123	5,640	<0.1	0	0	NC	INCO (3)
Ni-Cr-Cu-Mo No. 1, cast	S	123	5,640	<0.1	0	0	NC	INCO (3)
Ni-Cr-Cu-Mo No. 1, cast	W	403	5,640	<0.1	0	0	NC	INCO (3)
Ni-Cr-Cu-Mo No. 1, cast	S	403	6,780	<0.1	0	0	NC	INCO (3)
Ni-Cr-Cu-Mo No. 1, cast	W	751	5,640	<0.1	0	0	NC	INCO (3)
Ni-Cr-Cu-Mo No. 1, cast	S	751	5,640	<0.1	0	0	NC	INCO (3)
Ni-Cr-Cu-Mo No. 1, cast	W	1,064	5,300	<0.1	0	I	I-C	INCO (3)
Ni-Cr-Cu-Mo No. 1, cast	S	1,064	5,300	<0.1	0	0	NC	INCO (3)
Ni-Cr-Cu-Mo No. 1, cast	W	197	2,340	<0.1	0	0	NC	INCO (3)
Ni-Cr-Cu-Mo No. 1, cast	S	197	2,340	<0.1	0	I	I-C	INCO (3)
Ni-Cr-Cu-Mo No. 1, cast	W	402	2,370	<0.1	0	8	C	INCO (3)
Ni-Cr-Cu-Mo No. 1, cast	S	402	2,370	<0.1	0	0	NC	INCO (3)
Ni-Cr-Cu-Mo No. 1, cast	W	181	5	0.5	0	20	C	INCO (3)
Ni-Cr-Cu-Mo No. 1, cast	W	366	5	<0.1	0	I	I-C	INCO (3)
Ni-Cr-Cu-Mo No. 2, cast	W	123	5,640	<0.1	0	0	NC	INCO (3)
Ni-Cr-Cu-Mo No. 2, cast	S	123	5,640	<0.1	0	0	NC	INCO (3)
Ni-Cr-Cu-Mo No. 2, cast	W	403	6,780	<0.1	0	0	NC	INCO (3)
Ni-Cr-Cu-Mo No. 2, cast	S	403	6,780	<0.1	0	I	I-C	INCO (3)
Ni-Cr-Cu-Mo No. 2, cast	W	751	5,640	<0.1	0	I	I-C	INCO (3)
Ni-Cr-Cu-Mo No. 2, cast	S	751	5,640	<0.1	0	0	NC	INCO (3)
Ni-Cr-Cu-Mo No. 2, cast	W	1,064	5,300	0.1	0	3	C	INCO (3)
Ni-Cr-Cu-Mo No. 2, cast	S	1,064	5,300	0.1	0	5	C	INCO (3)
Ni-Cr-Cu-Mo No. 2, cast	W	197	2,340	0.1	0	I	I-C	INCO (3)
Ni-Cr-Cu-Mo No. 2, cast	S	197	2,340	<0.1	0	I	I-C	INCO (3)
Ni-Cr-Cu-Mo No. 2, cast	W	402	2,370	0.2	3	0	P	INCO (3)
Ni-Cr-Cu-Mo No. 2, cast	S	402	2,370	<0.1	0	I	I-C	INCO (3)
Ni-Cr-Cu-Mo No. 2, cast	W	181	5	0.1	0	18	C	INCO (3)
Ni-Cr-Cu-Mo No. 2, cast	W	366	5	0.1	0	27	C	INCO (3)
Ni-Cr-Mo, cast	W	123	5,640	<0.1	0	0	NC	INCO (3)
Ni-Cr-Mo, cast	S	123	5,640	<0.1	0	0	NC	INCO (3)
Ni-Cr-Mo, cast	W	403	6,780	<0.1	0	I	I-C	INCO (3)
Ni-Cr-Mo, cast	S	403	6,780	<0.1	0	I	I-C	INCO (3)
Ni-Cr-Mo, cast	W	751	5,640	<0.1	0	0	NC	INCO (3)
Ni-Cr-Mo, cast	S	751	5,640	<0.1	0	0	NC	INCO (3)
Ni-Cr-Mo, cast	W	1,064	5,300	<0.1	0	0	NC	INCO (3)

Continued

Table 54. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Corrosion Maximum Pit Depth (mils)	Corrosion Crevice Depth[b] (mils)	Corrosion Type[b]	Source[c]
Ni-Cr-Mo, cast	S	1,064	5,300	<0.1	0	0	NC	INCO (3)
Ni-Cr-Mo, cast	W	197	2,340	<0.1	0	0	NC	INCO (3)
Ni-Cr-Mo, cast	S	197	2,340	<0.1	0	I	I-C	INCO (3)
Ni-Cr-Mo, cast	W	402	2,370	<0.1	0	I	I-C	INCO (3)
Ni-Cr-Mo, cast	S	402	2,370	<0.1	0	I	I-C	INCO (3)
Ni-Cr-Mo, cast	W	181	5	<0.1	0	0	NC	INCO (3)
Ni-Cr-Mo, cast	W	366	5	<0.1	0	0	NC	INCO (3)
Ni-Cr-Mo-Si, cast	W	123	5,640	<0.1	0	0	NC	INCO (3)
Ni-Cr-Mo-Si, cast	S	123	5,640	<0.1	0	0	NC	INCO (3)
Ni-Cr-Mo-Si, cast	W	403	6,780	<0.1	0	0	NC	INCO (3)
Ni-Cr-Mo-Si, cast	S	403	6,780	<0.1	0	0	NC	INCO (3)
Ni-Cr-Mo-Si, cast	W	751	5,640	<0.1	0	0	NC	INCO (3)
Ni-Cr-Mo-Si, cast	S	751	5,640	<0.1	0	0	NC	INCO (3)
Ni-Cr-Mo-Si, cast	W	1,064	5,300	<0.1	0	0	NC	INCO (3)
Ni-Cr-Mo-Si, cast	S	1,064	5,300	<0.1	0	0	NC	INCO (3)
Ni-Cr-Mo-Si, cast	W	197	2,340	<0.1	0	0	NC	INCO (3)
Ni-Cr-Mo-Si, cast	S	197	2,340	<0.1	0	0	NC	INCO (3)
Ni-Cr-Mo-Si, cast	W	402	2,370	<0.1	0	0	NC	INCO (3)
Ni-Cr-Mo-Si, cast	S	402	2,370	<0.1	0	0	NC	INCO (3)
Ni-Cr-Mo-Si, cast	W	181	5	<0.1	0	0	NC	INCO (3)
Ni-Cr-Mo-Si, cast	S	366	5	<0.1	0	0	NC	INCO (3)
RL-35-100, cast	W	123	5,640	0.3	0	0	G	INCO (3)
RL-35-100, cast	S	123	5,640	0.5	0	0	G	INCO (3)
RL-35-100, cast	W	403	6,780	<0.1	0	0	G	INCO (3)
RL-35-100, cast	S	403	6,780	0.3	0	0	G	INCO (3)
RL-35-100, cast	W	751	5,640	<0.1	0	0	U-ET	INCO (3)
RL-35-100, cast	S	751	5,640	0.3	0	0	ET	INCO (3)
RL-35-100, cast	W	1,064	5,300	0.7	0	0	G	INCO (3)
RL-35-100, cast	S	1,064	5,300	0.1	0	0	G	INCO (3)
RL-35-100, cast	W	197	2,340	<0.1	0	0	NC	INCO (3)
RL-35-100, cast	S	197	2,340	<0.1	0	0	NU-ET	INCO (3)

[a]W = Totally exposed in seawater on sides of structure; S = Exposed in base of structure so that the lower portions of the specimen were embedded in the bottom sediments.

[b]Symbols for types of corrosion:

C	= Crevice	NC	= No visible corrosion
E	= Edge	NU	= Nonuniform
ET	= Etched	P	= Pitted
G	= General	SL	= Slight
I	= Incipient	U	= Uniform

[c]Numbers refer to references at end of report.

Table 55. Stress Corrosion of Miscellaneous Stainless Steels

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed	Source[a]
20 Cb	16	35	123	5,640	3	0	CEL (4)
20 Cb	24	50	123	5,640	3	0	CEL (4)
20 Cb	35	75	123	5,640	3	0	CEL (4)
20 Cb	24	50	403	6,780	2	0	CEL (4)
20 Cb	35	75	403	6,780	2	0	CEL (4)
20 Cb	16	35	751	5,640	3	0	CEL (4)
20 Cb	24	50	751	5,640	3	0	CEL (4)
20 Cb	35	75	751	5,640	3	0	CEL (4)
20 Cb	24	50	197	2,340	3	0	CEL (4)
20 Cb	35	75	197	2,340	3	0	CEL (4)
20 Cb	24	50	402	2,370	3	0	CEL (4)
20 Cb	35	75	402	2,370	3	0	CEL (4)

[a]Numbers refer to references at end of report.

Table 56. Changes in Mechanical Properties of Miscellaneous Stainless Steels

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[b]
				Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
20 Cb	S	123	5,640	92	+5	47	+19	40	-5	CEL (4)
20 Cb	W	403	6,780	92	+2	47	+4	40	-3	CEL (4)
20 Cb	S	403	6,780	92	+1	47	+1	40	-2	CEL (4)
20 Cb	W	751	5,640	92	+1	47	0	40	-2	CEL (4)
20 Cb	S	751	5,640	92	+2	47	+6	40	-5	CEL (4)
20 Cb	S	1,064	5,300	92	+4	47	+9	40	-3	CEL (4)
20 Cb	W	197	2,340	92	-1	47	-1	40	+4	CEL (4)
20 Cb	S	197	2,340	92	0	47	+1	40	-5	CEL (4)
20 Cb	W	402	2,370	92	0	47	-1	40	-7	CEL (4)
20 Cb	S	402	2,370	92	+4	47	+11	40	-12	CEL (4)
20 Cb	W	181	5	92	+2	47	+5	40	-4	CEL (4)
20 Cb	W	365	5	92	-2	47	-4	40	+1	CEL (4)

[a]W = Totally exposed in seawater on sides of structure; S = Exposed in base of structure so that the lower portions of the specimen were embedded in the bottom sediments.

[b]Numbers refer to references at end of report.

SECTION 6

ALUMINUM ALLOYS

The resistance of aluminum and its alloys to corrosion is due to a relatively chemically inert film of aluminum oxide which forms on its surface. As long as this oxide film remains intact the good corrosion resistance is preserved. In oxidizing environments where a sufficient amount of oxidizing agent or oxygen is present to repair any breaks in this protective film, the corrosion resistance of the aluminum alloys is maintained. The usual corrosion protection (passive) film that forms on aluminum in waters at temperatures below 70°C is bayerite (β-Al_2O_3-$3H_2O$).

In general, oxidizing conditions favor the preservation of this passive film, while reducing conditions destroy it. Chloride ions are particularly agressive in destroying this passive film.

When aluminum is immersed in water, the oxide film thickens much more rapidly than it does in air. The rate of growth decreases with time and reaches a limiting thickness which depends on the temperature, the oxygen content of the water, the ions present, and the pH. In seawater this naturally formed protective film breaks down more readily, and its repair and growth are retarded by the chloride ion.

The corrosion of aluminum alloys in seawater is usually of the pitting and crevice types. Pits begin by breakdown of the protective film at weak spots or at nonhomogeneities. The breakdown is followed by the formation of an electrolytic cell, the anode of which is a minute area of active metal and the cathode of which is a considerable area of passive metal. The large potential difference of this "passive-active" cell accounts for the considerable flow of current with its attendant rapid corrosion at the small anode (pitting).

Pitting is most likely to occur in the presence of chloride ions (for example, in seawater), combined with such cathodic depolarizers as oxygen or oxidizing salts. An oxidizing environment is usually necessary for preservation of a passive protective film with accompanying high corrosion resistance, but, unfortunately, it is also a condition for the occurrence of pitting. The oxidizer can often act as a depolarizer for "passive-active" cells established by the breakdown of passivity at a specific point or area. The chloride ion in particular can accomplish this breakdown.

As discussed above, aluminum alloys generally corrode in seawater by pitting and crevice corrosion; therefore, as much as 90 to 95% of the exposed surface can be uncorroded. With such low percentages of the total exposed area affected, corrosion rates calculated from weight losses as mils penetration per year (mpy) can give a very misleading picture. The mpy implies an uniform decrease in thickness, which for aluminum alloys is not the case.

Another manifestation of localized attack in aluminum alloys is oxygen concentration cell corrosion in crevices (usually known as crevice corrosion). This type of corrosion occurs underneath deposits of any kind on the metal surface, underneath barnacles, and at the faying surfaces of joints. The area of the aluminum alloys which is shielded from the surrounding solution becomes deficient in oxygen, thus creating a difference in oxygen concentration between the shielded and unshielded areas. An electrolytic cell is created with a difference in electrical potential being generated between the high and low oxygen concentration areas; the low concentration area becomes the anode of the cell. Corrosion occurs at the small anodic area and, because the cathodic area is much larger, the rate of attack is considerably greater than if no such cell were present.

There are two other types of localized corrosion often found in aluminum alloys: intergranular and exfoliation. Intergranular (intercrystalline) attack is selective corrosion of grain boundaries or closely adjacent regions without appreciable attack of the grains or crystals themselves. Exfoliation is a lamellar form of corrosion, resulting from a rapid lateral attack along grain boundaries or striations within the grains parallel to the metal surface. This directional attack results in a leafing action, aggravated by the voluminous corrosion products that causes the uncorroded strata to be split apart.

Low weight losses and low corrosion rates accompany these manifestations of localized corrosion. Thus, the integrity of an aluminum alloy structure will be jeopardized if designed solely on the basis of corrosion rates calculated from weight losses rather than on the basis of measured depths of pits and depths of crevice corrosion. Pitting and crevice corrosion can, and do, penetrate aluminum alloys rapidly in seawater, thus rendering them useless in short periods of time.

Therefore, corrosion rates expressed as mils penetration per year calculated from weight losses, maximum pit depths, maximum depths of crevice corrosion and other type of corrosion are tabulated to provide an overall picture of the corrosion of the aluminum alloys.

6.1. 1000 SERIES ALUMINUM ALLOYS (99.00% MINIMUM ALUMINUM)

The chemical compositions of the 1000 Series aluminum alloys are given in Table 57, their corrosion rates and type of corrosion in Table 58, their stress corrosion behavior in Table 59, and the effect of exposure on their mechanical properties in Table 60.

The 1000 Series aluminum alloys contain a minimum of 99% aluminum and are considered unalloyed aluminums.

The 1000 Series aluminum alloys corroded by the localized types of corrosion, pitting, and crevice.

6.1.1. Duration of Exposure

The corrosion rates of 1100 alloy decreased with increasing duration of exposure at the surface, in seawater at the 2,500-foot depth, and in the bottom sediments at the 6,000-foot depth, while the reverse occurred in the bottom sediments at the 2,500-foot depth and in the seawater at the 6,000-foot depth. There was no correlation between the severity of crevice corrosion and duration of exposure. The same was true for the severity of pitting corrosion, except at the surface where the maximum depth of pitting corrosion increased with increasing duration of exposure over a period of 1 year.

The corrosion of 1180 alloy was comparable to that of the 1100 alloy.

6.1.2. Effect of Depth

The corrosion rates of 1100 alloy increased with increasing depth after 1 year of exposure. However, there were no correlations between maximum depths of pitting and crevice corrosion and corrosion rates. In general, pitting and crevice corrosion were more severe at depth than at the surface.

There was no definite effect of depth on the corrosion of 1000 Series aluminum alloys.

6.1.3. Effect of Concentration of Oxygen

Changes in the concentration of oxygen in seawater had no definite or consistent effect on the corrosion of 1100 aluminum alloy. In general, after 1 year of exposure the corrosion rates and severity of crevice corrosion were greater at the lower oxygen concentrations, while the severity of pitting corrosion was greatest at the highest oxygen concentration.

6.1.4. Stress Corrosion

Alloys 1100 and 1180 were exposed at the 2,500-foot depth for 402 days when stressed at values equivalent to 50 and 75% of their respective yield strengths (Table 59) to determine their susceptibilities to stress corrosion. They were not susceptible to stress corrosion under the conditions of the test.

6.1.5. Mechanical Properties

The effects of exposure on the mechanical properties of 1100 and 1180 alloys are given in Table 60. Their mechanical properties were not affected by exposure in seawater at the 2,500-foot depth for 402 days.

6.2. 2000 SERIES ALUMINUM ALLOYS (ALUMINUM-COPPER ALLOYS)

The chemical compositions of the 2000 Series aluminum alloys are given in Table 61, their corrosion rates and type of corrosion in Table 62, their stress corrosion behavior in Table 63, and the effect of exposure on their mechanical properties in Table 64.

The 2000 Series aluminum alloys contain copper as the chief alloying element. Copper is one of the most important alloying metals for aluminum because of its appreciable solubility and its strengthening effect.

The 2000 Series alloys corroded by pitting, crevice, intergranular, and exfoliation types of corrosion.

6.2.1. Duration of Exposure

There was no definite or consistent correlation between corrosion rates and types of corrosion of the 2000 Series alloys and duration of exposure.

6.2.2. Effect of Depth

In general, corrosion rates were greater, and pitting, crevice, and intergranular corrosion were more severe at depth than at the surface after 1 year of exposure. Thus, seawater at depth is more aggressive to the 2000 Series aluminum alloys than is seawater at the surface.

6.2.3. Effect of Concentration of Oxygen

The effect of changes in the concentration of oxygen in seawater on the corrosion behavior of the 2000 Series alloys was inconsistent and erratic except for alloy 2219-T81. The corrosion rates, maximum depths of pits, and maximum depths of crevice corrosion decreased with increasing oxygen concentration, but not linearly, after 1 year of exposure. This behavior of alloy 2219-T81 shows that the concentration of oxygen in seawater exerts considerable influence on the corrosion of this alloy.

6.2.4. Stress Corrosion

The 2000 Series aluminum alloys were exposed at the depths and for the times shown in Table 63 when stressed at values equivalent to 30, 50, or 75% of their respective yield strengths to determine their susceptibilities to stress corrosion. They were not susceptible to stress corrosion under the test conditions.

6.2.5. Other Types of Corrosion

Alloys 2014-T3, 2014-T6, 2024-T3, 2024-T81, 2219-T81, and 2219-T87 were attacked by intergranular corrosion. Alloys 2014-T3, 2024-T3, 2024-T6, 2024-T81, and 2219-T81 were attacked by the exfoliation type of corrosion.

6.2.6. Welding

Welding did not affect the corrosion behavior of aluminum alloys 2024-T3 and 2219-T81.

6.2.7. Mechanical Properties

The effects of exposure on the mechanical properties of the 2000 Series aluminum alloys are given in Table 64. The mechanical properties of the 2000 Series alloys were impaired except for those of alloy Alclad 2024-T3.

6.3. 3000 SERIES ALUMINUM ALLOYS (ALUMINUM-MANGANESE ALLOYS)

The chemical compositions of the 3000 Series aluminum alloys are given in Table 65, their corrosion rates and types of corrosion in Table 66, their stress corrosion behavior in Table 67, and the effect of exposure on their mechanical properties in Table 68.

The chief alloying element of the 3000 Series aluminum alloys is manganese. Manganese is added to aluminum in amounts above 1% to increase its strength.

The 3000 Series alloys corroded chiefly by the crevice and pitting types of localized corrosion. There was also some blistering of the Alclad 3003 alloy.

6.3.1. Duration of Exposure

The corrosion rates of alloys 3003 and Alclad 3003 neither increased nor decreased uniformly with increasing duration of exposure, except for Alclad 3003 at the 2,500-foot depth. At this depth the corrosion rates decreased with increasing duration of exposure. In general, the severity of pitting and crevice corrosion was greater after the longer times of exposure.

The corrosion behavior of the 3000 Series alloys was erratic and unpredictable with regard to duration of exposure.

6.3.2. Effect of Depth

After 1 year of exposure the corrosion rates and maximum depths of pits increased with increasing depth, but not linearly. Alclad 3003 did not behave in this manner. In other words, the corrosion behavior of alloy 3003 appears to be depth (pressure) dependent in that it increased in severity with increasing depth.

6.3.3. Effect of Concentration of Oxygen

The corrosion rates, maximum pit depths, and maximum depths of crevice corrosion on alloys 3003 and Alclad 3003 due to changes in the concentration of oxygen in seawater were erratic.

6.3.4. Stress Corrosion

Alloy 3003-H14 was not susceptible to stress corrosion when stressed at values equivalent to 50 and 75% of its yield strength and exposed at the 2,500-foot depth for 402 days as given in Table 67.

6.3.5. Corrosion Products

Corrosion products from alloy 3003-H14 were analyzed by X-ray diffraction, spectrographic analysis, quantitative chemical analysis, and infra-red spectrophotometry. The qualitative results were: amorphous $Al_2O_3 \cdot XH_2O$, NaCl, SiO_2, Al, Na, Si, Mg, Fe, Cu, Ca, Mn, 3.58% chloride ion, 18.77% sulfate ion, and considerable phosphate ion.

6.3.6. Mechanical Properties

The effects of exposure on the mechanical properties of alloys 3003-H14, Alclad 3003-H12, and Alclad 3003-H14 are given in Table 68. In general, the mechanical properties of alloys 3003-H14 and Alclad 3003-H12 were adversely affected by exposure at depth.

6.4. 5000 SERIES ALUMINUM ALLOYS (ALUMINUM-MAGNESIUM ALLOYS)

The chemical compositions of the 5000 Series aluminum alloys are given in Table 69, their corrosion rates and types of corrosion in Table 70, their stress corrosion behavior in Table 71, and the effect of exposure on their mechanical properties in Table 72.

Aluminum is alloyed with magnesium to form an important class of nonheat-treatable alloys (5000 Series). Their utility and importance are based on their resistance to corrosion, high strength without heat treatment, and good weldability.

The 5000 Series aluminum alloys corroded chiefly by the crevice and pitting types of localized corrosion. Other types of corrosion found were: blistering, crater, edge, intergranular, line, and exfoliation.

6.4.1. Duration of Exposure

The general effect of duration of exposure on the corrosion of the 5000 Series alloys was erratic and nonuniform. The corrosion rates and the maximum depths of pitting or crevice corrosion neither increased nor decreased consistently with increasing duration of exposure; in many cases, the behavior was erratic.

6.4.2. Effect of Depth

After 1 year of exposure the average corrosion rates of all the 5000 Series alloys increased with depth, but not linearly. Also, the maximum depths of pits of all the alloys increased linearly with depth. The maximum depth of crevice corrosion of all the alloys increased with depth, but not consistently. The corrosion behavior of the 5000 Series aluminum alloys appears to be more uniformly affected by depth than by duration of exposure or changes in the concentration of oxygen in seawater.

6.4.3. Effect of Concentration of Oxygen

The corrosion rates of alloy 5086-H34 increased linearly with increasing concentration of oxygen in seawater, but the slope of the line was very small (1 to 25). However, such relationships were not found for the maximum depths of pitting and crevice corrosion. The pit depths were a maximum at the highest oxygen concentration, and the maximum depth of crevice corrosion was at the intermediate oxygen concentration.

The corrosion rates of alloy 5456-H321 decreased linearly with increasing concentration of oxygen in seawater, but the slope of the line was very small (1 to 10). However, no correlations were possible between maximum depth of pitting and crevice corrosion.

The corrosion rates and changes in the maximum depths of pits and crevice corrosion of the other 5000 Series aluminum alloys were erratic and inconsistent with respect to changes in the concentration of oxygen in seawater. Changes in the concentration of oxygen in seawater did not exert a constant or uniform influence on the corrosion behavior of the 5000 Series aluminum alloys. This behavior, like that of the stainless steels and some nickel alloys, can be attributed to the dual role oxygen can play with regard to alloys which depend upon passive films for their corrosion resistance.

6.4.4. Stress Corrosion

Some 5000 Series aluminum alloys were exposed at the depths and for the times given in Table 71 when stressed at values equivalent to 30, 50, or 75% of their respective yield strengths to determine their susceptibilities to stress corrosion. They were not susceptible to stress corrosion under the test conditions.

6.4.5. Other Types of Corrosion

Alloys 5052-H32 and 5456-H34 were attacked by the exfoliation type of corrosion. Alloys 5083-H113, 5086-H32, and 5086-H34 were attacked by intergranular corrosion.

6.4.6. Welding

Welding did not affect the corrosion behavior of alloys 5083-H113, 5086-H34, and 5454-H32.

6.4.7. Corrosion Products

Corrosion products from alloy 5086 were analyzed by X-ray diffraction, spectrographic analysis, quantitative chemical analysis, and infra-red spectrophotometry. The qualitative results were: amorphous $Al_2O_3 \cdot XH_2O$, NaCl, SiO_2, Al, Na, Mg, Cu, Fe, Si, Ti, 5.8% chloride ion, 26.2% sulfate ion, and considerable phosphate ion.

6.4.8. Mechanical Properties

The effects of exposure on the mechanical properties of the 5000 Series aluminum alloys are given in Table 72. The mechanical properties of the following alloys were adversely affected by exposure: 5456-H321 after 123 days of exposure at the 6,000-foot depth; 5052-H32, 5083-H113, and 5456-H34 after 403 days of exposure at the 6,000-foot depth; and 5456-H321 and 5456-H34 after 751 days of exposure at the 6,000-foot depth. The mechanical properties of the above alloys after exposures for different times at different depths and of the other alloys were not adversely affected by exposure at depth in the seawater.

6.5. 6000 SERIES ALUMINUM ALLOYS (ALUMINUM-MAGNESIUM-SILICON ALLOYS)

The chemical compositions of the 6000 Series aluminum alloys are given in Table 73, their corrosion rates and types of corrosion in Table 74, their stress corrosion behavior in Table 75, and the effects of exposure on their mechanical properties in Table 76.

The aluminum-magnesium-silicon system is the basis for a major class of heat-treatable aluminum-base alloys. They combine many desirable characteristics, including moderately high strength and good resistance to corrosion.

There was only one 6000 Series alloy (6061) in this program. Alloy 6061 corroded chiefly by the crevice and pitting types of localized corrosion. Also, there was some intergranular corrosion.

6.5.1. Duration of Exposure

The corrosion rates of 6061 at the surface and at the 6,000-foot depth decreased with duration of exposure, but not uniformly, while those at the 2,500-foot depth increased with duration of exposure. However, the maximum depths of pitting and crevice corrosion increased with increasing duration of exposure at the surface and at depths of 2,500 and 6,000 feet.

6.5.2. Effect of Depth

Although the corrosion rates and the maximum depths of pitting and crevice corrosion were greater at depth than at the surface, these increases did not increase uniformly with increasing depth. Depth exerted no uniform influence on the corrosion behavior of alloy 6061.

6.5.3. Effect of Concentration of Oxygen

The corrosion rates and maximum depths of pitting and crevice corrosion decreased with increasing concentration of oxygen in seawater. The maximum depths of crevice corrosion decreased linearly with increasing oxygen concentration. The corrosion rates and maximum depths of pitting decreased constantly, but not uniformly, with depth.

6.5.4. Stress Corrosion

Alloy 6061-T6 was exposed at the depths and for the times given in Table 75 when stressed at values equivalent to 30 and 75% of its yield strength to determine its susceptibility to stress corrosion. Alloy 6061-T6 was not susceptible to stress corrosion under the test conditions.

6.5.5. Welding

The corrosion of alloy 6061-T6 was adversely affected by welding. Alloy 6061 was attacked by intergranular corrosion in the "as-welded" condition.

6.5.6. Mechanical Properties

The effects of exposure on the mechanical properties of alloy 6061-T6 are given in Table 76. The mechanical properties of 6061-T6 were adversely affected by exposure in seawater. Those specimens which had been welded and which had been attacked by intergranular corrosion were the most seriously affected.

6.6. 7000 SERIES ALUMINUM ALLOYS (ALUMINUM-ZINC-MAGNESIUM ALLOYS)

The chemical compositions of the 7000 Series aluminum alloys are given in Table 77, their corrosion rates and types of corrosion in Table 78, their stress corrosion behavior in Table 79, and the effect of exposure on their mechanical properties in Table 80.

Combinations of zinc and magnesium in aluminum provide a class of heat-treatable alloys, some of which develop the highest strengths presently known for commercial aluminum-base alloys. The addition of copper to the aluminum-zinc-magnesium system, together with small but important amounts of chromium and manganese, results in the highest strength, heat-treatable, aluminum-base alloys commercially available.

The 7000 Series alloys were attacked by crevice, edge, exfoliation, intergranular, and pitting types of corrosion. Corrosion of the Alclad alloys was by shallow pitting and crevice corrosion, slight blistering, and general corrosion.

Because of the erratic behavior of the 7000 Series aluminum alloys during exposure in seawater at depth, it was impossible to find any correlation between their corrosion behavior and duration of exposure, effect of depth, or the effect of changes in the concentration of oxygen in seawater.

A practical case of unusual corrosion on an aluminum alloy was encountered with the Alclad 7178-T6 aluminum alloy buoys used in the installation of the STU structures. During the retrieval of STU 1-3 after 123 days of exposure, the buoy, which was 300 feet below the surface, was found to be corroded. White corrosion products on the bottom hemisphere covered areas where the cladding alloy had corroded through to the core material. The top hemisphere was blistered, the blisters being as large as 2 inches in diameter and 0.75 inch high with a hole in the top of each blister. The hole in the top of the blister indicates the origin of the failure: originally a pinhole in the cladding alloy existed where seawater gained access to the interface between the cladding alloy and the core alloy. When this blister was sectioned to inspect the corrosion underneath, it was found to be filled with white crystalline aluminum oxide corrosion products. It appeared that seawater penetrated the cladding alloy at a defect, or a pit was initiated at a particle of a cathodic metal (probably iron), and the corrosion was then concentrated at the interface between the two alloys (cladding alloy and core alloy). The thickness of the remaining Alclad layer indicated that it had not been sacrificed to protect the core alloy as was its intended function. On the other hand, the selective corrosion of the Alclad layer on the bottom hemisphere and the uncorroded core material showed that, in this case, the cladding alloy was being sacrificed to protect the core material as intended.

When an attempt was made to repair these buoys for reuse by grinding off all traces of corrosion prior to painting, it was found that the corrosion had penetrated along the interface between the cladding alloy and the core alloy for considerable distances from the edges of the blisters and the edges of the holes where the cladding alloy layer had been sacrificed. Polished transverse sections taken from the buoy through these corroded areas corroborated the indications found from grinding operations. Metallurgical examinations showed that the corroded paths were, in fact, entirely in the cladding alloy, with a thin diffusion layer of material between the corrosion path and the core material.

Blistering of Alclad aluminum alloys such as encountered with these Alclad 7178-T6 spheres was very unusual. Blistering due to corrosion and the rapid rate of sacrifice of Alclad layers had not been encountered previously by the author and other investigators in surface seawater applications. Because of this unique blistering one of the spheres was sent to the Research Laboratories of the Aluminum Company of America where an investigation was made to determine the mechanism of this behavior.

Wei [15] showed that there was preferential diffusion of zinc over copper from the core alloy into this interfacial zone. The high zinc and low copper contents of this interfacial zone rendered it anodic to both the cladding and core alloys. Selective attack was inevitable once corrosion reached this anodic diffusion zone.

That this type of blistering has been encountered on buoys at depths from 300 to 6,800 feet emphasizes the fact that there is some factor present which either is more influential at depth or is not present at the surface. The fact that this thin anodic zone is probably present in all Alclad 7178-T6 products and, as such, is not blistered during surface seawater exposures indicates that the seawater environments at depths of 300 feet and greater differ from the seawater environments at the surface, at least with respect to the corrosion behavior of this alloy.

6.6.1. Stress Corrosion

The 7000 Series aluminum alloys were exposed at the depths and for the times given in Table 79 when stressed at values equivalent to 30, 50, and 75% of their respective yield strengths to determine their susceptibilities to stress corrosion. Alloys 7075-T6, 7079-T6, Alclad 7079-T6, and 7178-T6, failed by stress corrosion cracking.

6.6.2. Corrosion Products

Corrosion products from alloy 7079-T6 were analyzed by X-ray diffraction, spectographic analysis, quantitative chemical analysis, and infra-red spectrophotometry. The qualitative results were: amorphorous $Al_2O_3 \cdot XH_2O$, NaCl, Al metal, Al, Cu, Mg, Mn, Zn, Na, Ca, traces of Ti and Ni, 2.82% chloride ion, 16.7% sulfate ion, and considerable phosphate ion.

6.6.3. Mechanical Properties

The effects of exposure on the mechanical properties of the 7000 Series aluminum alloys are given in Table 80. The mechanical properties of alloys 7002-T6, 7039-T6, 7075-T6, 7075-T64, 7075-T73, 7079-T6, and 7178-T6 were adversely affected.

Table 57. Chemical Composition of 1000 Series Aluminum Alloys, Percent by Weight

Alloy	Gage (in.)	Si	Fe	Cu	Mn	Zn	Al[a]
1100	—	—	—	—	—	—	99.0
1100-0	—	*b*	*b*	0.14	0.03	—	R
1100-H14	0.050	0.14	0.55	0.14	—	0.06	R
1180	0.050	0.06	0.08	0.002	0.002	—	R

[a]R = remainder.

[b]Si + Fe = 0.57

Table 58. Corrosion Rates and Types of Corrosion of 1000 Series Aluminum Alloys

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion				Source[c]
				Rate (mpy)	Maximum Pit Depth (mils)	Crevice Depth[b] (mils)	Type[b]	
1100-H14	W	123	5,640	2.0	39	0	P	INCO (3)
1100-H14	S	123	5,640	3.1	41	0	P	INCO (3)
1100-H14	W	403	6,780	4.2	0	62	C (PR)	INCO (3)
1100-H14	S	403	6,780	1.3	62	62	C (PR); P (PR)	INCO (3)
1100-H14	W	751	5,640	4.5	0	62	C (PR)	INCO (3)
1100-H14	S	751	5,640	2.0	0	62	C (PR)	INCO (3)
1100-H14	W	1,064	5,300	3.0	0	62	C (PR)	INCO (3)
1100-H14	W	1,064	5,300	1.8	S-P	S-C	S-C; S-P	CEL (4)
1100-H14	S	1,064	5,300	1.0	0	62	C (PR)	INCO (3)
1100-H14	W	197	2,340	5.6	0	62	C (PR)	INCO (3)
1100-H14	W	197	2,340	<0.1	23	0	E; P	REY (14)
1100-H14	S	197	2,340	<0.1	I	I	I-C; I-P	INCO (3)
1100-H14	W	402	2,340	1.6	0	62	C (PR)	INCO (3)
1100-H14	W	402	2,370	0.9	I	50	C (PR); I-P	CEL (4)
1100-H14	S	402	2,370	0.5	26	26	C; P	INCO (3)
1100-H14	S	402	2,370	0.5	I	50	C (PR); I-P	CEL (4)
1100-H14	W	181	5	1.4	0	S	S-C	INCO (3)
1100-H14	W	366	5	0.6	13	13	C; P	INCO (3)
1180-H14	W	402	2,370	1.0	I	50	C (PR); I-P	CEL (4)
1180	W	402	2,370	<0.1	41	0	E; S-P	REY (14)
1180-H14	S	402	2,370	0.8	I	50	C (PR); I-P	CEL (4)

[a]W = Totally exposed in seawater on sides of structure; S = Exposed in base of structure so that the lower portions of the specimen were embedded in the bottom sediments.

[b]Symbols for types of corrosion:

C	= Crevice	P	= Pitting
E	= Edge	PR	= Perforated
I	= Incipient	S	= Severe

[c]Numbers refer to references at end of report.

Table 59. Stress Corrosion of 1000 Series Aluminum Alloys

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed	Source[a]
1100-H14	8	50	402	2,370	3	0	CEL (4)
1100-H14	12	75	402	2,370	3	0	CEL (4)
1180	6	50	402	2,370	3	0	CEL (4)
1180	10	75	402	2,370	3	0	CEL (4)

[a]Numbers refer to references at end of report.

Table 60. Changes in Mechanical Properties of 1000 Series Aluminum Alloys Due to Corrosion

Alloy	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[a]
			Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
1100-H14	402	2,370	19	-2	18	+3	7	+14	CEL (4)
1180	402	2,370	15	+1	14	+4	11	+1	CEL (4)

[a]Numbers refer to references at end of report.

Table 61. Chemical Composition of 2000 Series Aluminum Alloys, Percent by Weight

Alloy	Gage (in.)	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Other	Al[a]
2014-Te	–	0.80	0.34	3.90	0.70	0.50	0.01	0.01	0.03	–	–	R
2014-T6	0.050	0.91	0.53	4.23	0.80	0.32	0.03	0.01	0.08	0.02	–	R
2014-T6	–	0.84	0.35	4.43	0.80	0.66	–	–	–	–	–	R
2024	0.064	–	–	4.3	0.6	1.5	–	–	–	–	–	R
2024-T3+T81	–	0.20	0.20	4.50	0.80	1.50	0.02	0.04	0.06	0.01	–	R
Alclad 2024-T3[b]												
2219-T81	0.064	0.20	0.30	6.3	0.30	<0.02	–	–	0.10	0.06	0.10 V 0.17 Zr	R
2219-T81	–	0.05	0.15	4.00	0.10	0.05	0.05	0.10	0.05	0.05	–	R
2219-T87	0.040	0.08	0.12	6.54	0.26	<0.02	<0.02	<0.02	0.03	0.02	0.10 V 0.15 Zr	R
2219-T87	0.040	–	–	6.3	0.30	–	–	–	–	0.06	–	R

[a]R = remainder.
[b]No analysis given.

Table 62. Corrosion Rates and Types of Corrosion of 2000 Series Aluminum Alloys

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth[b] (mils)	Crevice Depth[b] (mils)	Type[b]	Weld[b]	
2014-T3	W	123	5,640	–	7	0	B; IG; P; XF	–	NADC (7)
2014-T3	W	751	5,640	–	PR	0	P (PR)	–	NADC (7)
2014-T6	W	403	6,780	–	S	S	S-C; S-P	–	NADC (7)
2014-T6	W	1,064	5,300	–	S	SH	SH-C; S-P	–	NADC (7)
2014-T6	S	1,064	5,300	–	PR	–	P (PR)	–	NADC (7)
2014-T6	W	197	2,340	–	10	0	IG; U-P; L	–	NADC (7)
2014-T6	W	197	2,340	<0.1	20	0	P	–	REY (14)
2014-T6	W	402	2,370	5.4	27	50	C (PR); IG; P	–	CEL (4)
2014-T6	S	402	2,370	3.5	25	50	C (PR); IG; P	–	CEL (4)
2024-0	W	123	5,640	5.2	28	0	P	–	INCO (3)
2024-0	S	123	5,640	3.4	27	0	P	–	INCO (3)
2024-0	W	403	6,780	6.2	62	0	P (PR)	–	INCO (3)
2024-0	S	403	6,780	1.2	0	55	S-C	–	INCO (3)
2024-0	W	751	5,640	2.8	65	65	C (PR); P (PR)	–	INCO (3)
2024-0	S	751	5,640	2.6	65	0	P (PR)	–	INCO (3)
2024-0	W	1,064	5,300	1.9	62	62	C (PR); P (PR)	–	INCO (3)
2024-0	S	1,064	5,300	1.6	55	0	S-P	–	INCO (3)
2024-0	W	197	2,340	3.1	19	0	S-E; P	–	INCO (3)
2024-0	S	197	2,340	<0.1	I	I	I-C; I-P	–	INCO (3)
2024-0	W	402	2,370	3.0	62	62	C (PR); P (PR)	–	INCO (3)
2024-0	S	402	2,370	0.8	0	0	E	–	INCO (3)
2024-0	W	181	5	3.8	32	32	C; P	–	INCO (3)
2024-0	W	366	5	4.1	34	34	C; P	–	INCO (3)
2024-T3	W	403	6,780	–	39	0	S-E; S-P	–	NADC (7)
2024-T3, anodized	W	751	5,640	–	0	0	G	–	NADC (7)
2024-T3	W	1,064	5,300	1.9	–	–	C; P; XF	–	CEL (4)
2024-T3[e]	W	197	2,340	–	30	0	SL-B; IG; U-P	HAZ (IG)	NADC (7)
2024-T3	W	402	2,370	–	39	0	E; L; P	–	NADC (7)
Alclad 2024-T3	W	123	5,640	–	I	0	I-P	–	NADC (7)
Alclad 2024-T3	W	751	5,640	–	0	0	G	–	NADC (7)
2024-T6	W	403	6,780	–	–	–	L; D-P; XF	–	NADC (7)

Continued

Table 62. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion					Source[c]
				Rate (mpy)	Maximum Pit Depth[b] (mils)	Crevice Depth[b] (mils)	Type[b]	Weld[b]	
2024-T81	W	123	5,640	–	40	0	B; EX-IG; CR; P	–	NADC (7)
2024-T81	W	403	6,780	–	62	0	S-P	–	NADC (7)
2024-T81, anodized	W	403	6,780	–	0	0	XF	–	NADC (7)
2024-T81, painted	W	403	6,780	–	0	0	NPF	–	NADC (7)
2024-T81	W	402	2,370	–	39	S	S-C; E; D-P; EX-XF	–	NADC (7)
2024-T81, anodized	W	402	2,370	–	0	MD	MD-C; EX-XF	–	NADC (7)
2219-T81	W	123	5,640	2.0	16	15	C; IG; G-P	–	CEL (4)
2219-T81[d]	W	123	5,640	–	40	0	EX-IG; P; XF	NC	NADC (7)
2219-T81	S	123	5,640	1.9	20	10	C; IG; G-P	–	CEL (4)
2219-T81	W	403	6,780	3.6	35	38	C; E; IG; G-P	–	CEL (4)
2219-T81	S	403	6,780	3.1	62	34	C; E; IG; P (PR)	–	CEL (4)
2219-T81	W	751	5,640	2.4	30	24	C; E; IG; G-P	–	CEL (4)
2219-T81[d]	W	751	5,640	–	PR	0	P (PR)	NC	NADC (7)
2219-T81	W	1,064	5,300	1.6	47	47	C; SL-E; IG; G-P	–	CEL (4)
2219-T81	S	1,064	5,300	1.5	48	0	IG; G-P	–	CEL (4)
2219-T81	W	197	2,340	2.6	25	0	SL-E; IG; G-P	–	CEL (4)
2219-T81	S	197	2,340	2.0	32	0	E; IG; G-P	–	CEL (4)
2219-T81	W	402	2,370	4.5	78	69	S-C; S-E; IG; S-P	–	CEL (4)
2219-T81	S	402	2,370	2.0	50	66	S-C; S-E; IG; S-P	–	CEL (4)
2219-T81	W	181	5	3.5	24	0	IG; G-P	–	CEL (4)
2219-T81	W	398	5	2.5	26	0	P	–	CEL (4)
2219-T81	W	540	5	1.4	48	32	C; P	–	CEL (4)
2219-T81	W	588	5	4.4	62	43	C; E; P	–	CEL (4)
2219-T87	W	197	2,340	<0.1	12	0	P	–	REY (14)
2219-T87	W	402	2,370	1.7	20	40	C (PR); IG; U-P	–	CEL (4)
2219-T87	S	402	2,370	1.1	16	40	C (PR); IG; U-P	–	CEL (4)

[a]W = Totally exposed in seawater on sides of structure; S= Exposed in base of structure so that the lower portions of the specimens were embedded in the bottom sediments.

[b]Symbols for types of corrosion:

B = Blisters	D = Deep	G = General	IG = Intergranular
C = Crevice	E = Edge	HAZ = Heat-affected zone	L = Line
CR = Crater	EX = Extensive	I = Incipient	MD = Moderate

Continued

Table 62. Continued.

[b] Footnote *b* continued:

NC	= No visible corrosion	PR	= Perforated	SL	= Slight
NPF	= No paint failure	S	= Severe	U	= Uniform
P	= Pitting	SH	= Shallow	XF	= Exfoliation

[c] Numbers refer to references at end of report.

[d] Welded with 2319 rod by the TIG process.

[e] Welded.

Table 63. Stress Corrosion of 2000 Series Aluminum Alloys

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed	Source[a]
2014-T6	17	30	197	2,340	3	0	NADC (7)
2014-T6	41	75	197	2,340	3	0	NADC (7)
2014-T6	31	50	402	2,370	3	0	CEL (4)
2014-T6	46	75	402	2,370	3	0	CEL (4)
2024-T3	15	30	403	6,780	3	*b*	NADC (7)
2024-T3	38	75	403	6,780	3	*b*	NADC (7)
2024-T3	15	30	197	2,340	3	0	NADC (7)
2024-T3	38	75	197	2,340	3	0	NADC (7)
2024-T81	15	30	402	2,370	3	0	NADC (7)
2024-T81	38	75	402	2,370	3	0	NADC (7)
2024-T81, anodized	15	30	402	2,370	3	0	NADC (7)
2024-T81, anodized	38	75	402	2,370	3	0	NADC (7)
2219-T81	25	50	402	2,370	3	0	CEL (4)
2219-T81	38	75	402	2,370	3	0	CEL (4)
2219-T87	25	50	402	2,370	3	0	CEL (4)
2219-T87	38	75	402	2,370	3	0	CEL (4)

[a]Numbers refer to references at end of report.

[b]Specimens lost at sea during exposure.

Table 64. Changes in Mechanical Properties of 2000 Series Aluminum Alloys Due to Corrosion

Alloy	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[a]
			Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
2014-T3	123	5,640	65	-54	–	–	20	-90	NADC (7)
2014-T6	123	5,640	72	-16	55	+8	20	-90	NADC (7)
2014-T6	751	5,640	72	-39	55	-22	20	-94	NADC (7)
2014-T6	1,064	5,300	72	-19	55	-40	20	-95	NADC (7)
2014-T6	197	2,340	72	-20	55	-4	20	-91	NADC (7)
2014-T6	402	2,370	68	-38	62	-28	11	-92	CEL (4)
2024-T3	403	6,780	62	-35	42	-10	17	-89	NADC (7)
2024-T3	751	5,640	62	+3	42	-4	17	-24	NADC (7)
2024-T3[b]	197	2,340	62	-100	42	-100	17	-100	NADC (7)
2024-T3	402	2,370	62	-26	42	-3	17	-96	NADC (7)
Alclad 2024-T3	123	5,640	62	0	42	0	17	+12	NADC (7)
2024-T81	123	5,640	72	-49	–	–	10	-95	NADC (7)
2024-T81	403	6,780	72	-10	–	–	10	-58	NADC (7)
2024-T81	402	2,370	72	-3	–	–	10	-55	NADC (7)
2219-T81[c,d]	123	5,640	62	+5	50	+2	8	+38	NADC (7)
2219-T81	123	5,640	66	-3	50	-1	11	-42	CEL (4)
2219-T81	403	6,780	66	-19	50	-12	11	-52	CEL (4)
2219-T81	751	5,640	66	-18	50	-14	11	-62	CEL (4)
2219-T81	1,064	5,300	66	-22	50	-16	11	-57	CEL (4)
2219-T81	197	2,340	66	-5	50	-6	11	-30	CEL (4)
2219-T81	402	2,370	66	-15	50	-14	11	-62	CEL (4)
2219-T81	181	5	65	-17	50	-13	12	-62	CEL (4)
2219-T87	402	2,370	61	-27	51	-29	10	-77	CEL (4)

[a] Numbers refer to references at end of report.

[b] Too severely corroded to machine into tensile specimens.

[c] Welded, 2319 electrode, TIG process.

[d] Transverse properties.

Table 65. Chemical Composition of 3000 Series Aluminum Alloys, Percent by Weight

Alloy	Gage (in.)	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Al[a]
3003	–	–	–	–	1.2	–	–	–	–	–	R
3003	–	0.15	0.45	0.15	1.25	–	–	–	0.05	–	R
3003-H12 & H14	–	0.10	0.20	0.05	1.10	0.03	0.01	0.01	0.02	0.01	R
3003-H14	0.125	0.60	0.70	0.20	1.25	–	–	–	0.10	–	R
3003-H14	0.063	0.20	0.58	0.13	1.05	<0.01	<0.01	<0.01	<0.01	–	R
3003-H14	0.063	0.15	0.50	0.10	1.30	0.02	–	–	0.07	–	R
3003-H24	–	0.10	0.48	0.16	1.10	–	–	–	0.08	–	R
Alclad 3003-H12	0.125										
Core		0.06	0.70	0.20	1.25	–	–	–	0.10	–	R
Cladding		*b*	*b*	0.10	0.10	0.10	–	–	1.0	–	R
Alclad 3003-H14	–	0.10	0.20	0.05	1.10	0.03	0.01	0.01	0.02	0.01	R

[a] R = remainder.

[b] Si + Fe = 0.70.

Table 66. Corrosion Rates and Types of Corrosion of 3000 Series Aluminum Alloys

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion				Source[c]
				Rate (mpy)	Maximum Pit Depth[b] (mils)	Crevice Depth[b] (mils)	Type[b]	
3003-H14	W	123	5,640	0.5	27	32	C; P	CEL (4)
3003	W	123	5,640	0.6	0	28	C	INCO (3)
3003-H14	S	123	5,640	1.9	55	68	C; E; P	CEL (4)
3003	S	123	5,640	3.6	0	50	C (PR)	INCO (3)
3003-H14	W	403	6,780	3.9	125	66	S-C; P (PR)	CEL (4)
3003	W	403	6,780	3.8	0	50	C (PR)	INCO (3)
3003-H14	S	403	6,780	3.7	125	52	S-C; P (PR)	CEL (4)
3003	S	403	6,780	1.3	0	50	C (PR)	INCO (3)
3003-H14	W	751	5,640	2.3	125	125	C (PR); P (PR)	CEL (4)
3003	W	751	5,640	3.0	0	40	C (PR)	INCO (3)
3003-H14	S	751	5,640	2.5	125	125	C (PR); P (PR)	CEL (4)
3003	S	751	5,640	1.8	0	40	C (PR)	INCO (3)
3003-H14	W	1,064	5,300	2.0	125	125	C (PR); S-E; P (PR)	CEL (4)
3003	W	1,064	5,300	2.8	–	–	*d*	INCO (3)
3003-H14	S	1,064	5,300	1.9	125	0	EX-E; P (PR)	CEL (4)
3003	S	1,064	5,300	1.0	0	50	C (PR)	INCO (3)
3003-H14	W	197	2,340	<0.1	17	0	E; P	REY (14)
3003-H14	W	197	2,340	2.4	48	28	C; S–E; P	CEL (4)
3003	W	197	2,340	1.4	0	40	C (PR)	INCO (3)
3003-H14	S	197	2,340	1.6	55	25	C; E; S-P	CEL (4)
3003	S	197	2,340	<0.1	I	I	I-C; I-P	INCO (3)
3003-H14	W	402	2,370	1.4	91	93	S-C; S-E; D-P	CEL (4)
3003	W	402	2,370	1.1	0	40	C (PR)	INCO (3)
3003-H14	S	402	2,370	1.7	115	70	S-C; D-P	CEL (4)
3003	S	402	2,370	0.5	0	50	C (PR)	INCO (3)
3003-H14	W	181	5	1.1	33	0	E; P	CEL (4)
3003	W	181	5	1.0	I	0	I-P	INCO (3)
3003	W	366	5	0.6	I	0	I-P	INCO (3)
3003-H14	W	398	5	1.0	21	0	P	CEL (4)
3003-H14	W	540	5	0.3	34	75	C; P	CEL (4)
3003-H14	W	588	5	2.0	65	0	P	CEL (4)
Alclad 3003-H14	W	123	5,640	–	I	0	I-P	NADC (7)
Alclad 3003-H12	W	123	5,640	0.2	18	15	B; C; SL-E; P[e]	CEL (4)
Alclad 3003	W	123	5,640	2.7	0	0	G	INCO (3)
Alclad 3003-H12	S	123	5,640	2.8	20	0	B; C; SL-E[e]	CEL (4)
Alclad 3003	S	123	5,640	2.6	0	0	G	INCO (3)
Alclad 3003-H12	W	403	6,780	0.4	13	14	C; SL-E; P	CEL (4)
Alclad 3003	W	403	6,780	2.5	0	0	G	INCO (3)
Alclad 3003-H12	S	403	6,780	0.2	14	13	C; SL-E; P	CEL (4)
Alclad 3003	S	403	6,780	0.4	0	0	*f*	INCO (3)
Alclad 3003-H14	W	751	5,640	–	0	0	SL-G	NADC (7)
Alclad 3003-H12	W	751	5,640	0.3	13	13	C; E; P	CEL (4)
Alclad 3003	W	751	5,640	1.4	0	0	G	INCO (3)
Alclad 3003-H12	S	751	5,640	2.4	14	14	C; E; P[e]	CEL (4)
Alclad 3003	S	751	5,640	1.5	0	0	U	INCO (3)
Alclad 3003-H12	W	1,064	5,300	0.5	20	13	C; P[g]	CEL (4)
Alclad 3003	W	1,064	5,300	1.5	0	0	U	INCO (3)

Continued

Table 66. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion				Source[c]
				Rate (mpy)	Maximum Pit Depth[b] (mils)	Crevice Depth[b] (mils)	Type[b]	
Alclad 3003-H12	S	1,064	5,300	0.8	16	13	C; P[h]	CEL (4)
Alclad 3003	S	1,064	5,300	0.6	0	0	U	INCO (3)
Alclad 3003-H12	W	197	2,340	2.2	15	13	C; P[e]	CEL (4)
Alclad 3003	W	197	2,340	2.3	0	0	G	INCO (3)
Alclad 3003-H12	S	197	2,340	1.1	14	13	C; P[i]	CEL (4)
Alclad 3003	S	197	2,340	<0.1	2	2	C; P	INCO (3)
Alclad 3003-H12	W	402	2,370	2.2	14	15	C; P[j]	CEL (4)
Alclad 3003	W	402	2,370	1.6	0	0	*k*	INCO (3)
Alclad 3003-H12	S	402	2,370	1.8	13	14	C; P[l]	CEL (4)
Alclad 3003	S	402	2,370	0.4	0	0	*m*	INCO (3)
Alclad 3003-H12	W	181	5	1.0	I	0	I-P	CEL (4)
Alclad 3003	W	181	5	1.0	2	0	N-P	INCO (3)
Alclad 3003	W	366	5	0.5	2	0	N-P	INCO (3)
Alclad 3003-H12	W	398	5	1.1	16	0	P	CEL (4)
Alclad 3003-H12	W	540	5	0.3	16	0	P	CEL (4)
Alclad 3003-H12	W	588	5	1.8	17	0	P	CEL (4)

[a]W = Totally exposed in sewater on sides of structure; S = Exposed in base of structure so that the lower portions of the specimens were embedded in the bottom sediments.

[b]Symbols for types of corrosion:

B	= Blisters	N	= Numerous
C	= Crevice	P	= Pitting
D	= Deep	PR	= Perforated
E	= Edge	S	= Severe
EX	= Extensive	SL	= Slight
G	= General	U	= Uniform
I	= Incipient		

[c]Numbers refer to references at end of report.

[d]About 40% of specimen missing.

[e]Large area of cladding gone.

[f]Nonuniform cladding loss.

[g]Nonuniform cladding loss, 18% gone, one area 7 sq. in.

[h]Nonuniform cladding loss, 13% gone, one area 5 sq. in.

[i]One 7-sq.-in. area of cladding gone from portion in water; cladding gone on 2-in.-high strip across bottom portion in bottom sediment.

[j]20% cladding gone and incipient pitting in denuded area.

[k]60% of cladding gone.

[l]18% of cladding gone, incipient pitting in denuded area; cladding gone on 2-in.-high strip across bottom portion embedded in bottom sediment.

[m]20% of cladding gone.

Table 67. Stress Corrosion of 3000 Series Aluminum Alloys

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed	Source[a]
3003-H14	6	50	402	2,370	3	0	CEL (4)
3003-H14	9	75	402	2,370	3	0	CEL (4)

[a]Numbers refer to references at end of report.

Table 68. Changes in Mechanical Properties of 3000 Series Aluminum Alloys Due to Corrosion

Alloy	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[a]
			Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
3003-H14	123	5,640	22	-4	20	-8	13	-43	CEL (4)
3003-H14	403	6,780	22	-48	20	-50	13	-77	CEL (4)
3003-H14	751	5,640	21	-20	21	-11	4	+25	NADC (7)
3003-H14	751	5,640	22	-24	20	-26	13	-72	CEL (4)
3003-H14	1,064	5,300	22	-3	20	-18	13	-20	CEL (4)
3003-H14	197	2,340	22	-6	20	-10	13	+15	CEL (4)
3003-H14	402	2,370	22	+6	20	+11	13	+5	CEL (4)
3003-H14	181	5	23	+4	21	-1	18	-1	CEL (4)
Alclad 3003-H12	123	5,640	19	-2	18	-1	14	-42	CEL (4)
Alclad 3003-H12	403	6,780	19	+3	18	-1	14	0	CEL (4)
Alclad 3003-H12	751	5,640	19	-3	18	-4	14	-19	CEL (4)
Alclad 3003-H12	1,064	5,300	19	+3	18	+1	14	-12	CEL (4)
Alclad 3003-H12	197	2,340	19	+1	18	+2	14	+7	CEL (4)
Alclad 3003-H12	402	2,370	19	+1	18	0	14	-14	CEL (4)
Alclad 3003-H12	181	5	19	+4	18	+1	14	+2	CEL (4)
Alclad 3003-H14	123	5,640	21	0	–	–	4	+100	NADC (7)

[a]Numbers refer to references at end of report.

Table 69. Chemical Composition of 5000 Series Aluminum Alloys, Percent by Weight

Alloy	Gage (in.)	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Al[a]
5050-H34	0.050	0.18	0.64	0.04	–	1.19	–	–	–	–	R
5052	–	–	–	–	–	2.5	0.25	–	–	–	R
5052-0, H32, H34	–	0.10	0.17	0.02	0.03	2.20	0.22	–	–	0.01	R
5052-H22	–	*b*	*b*	0.05	<0.01	2.50	0.23	–	0.07	–	R
5052-H34	0.050	0.13	0.30	0.02	–	2.31	0.22	–	–	–	R
5083	–	–	-	0.15	0.6	4.5	–	–	–	–	R
5083-H113	0.500	0.40	0.40	0.10	0.65	4.5	0.15	–	0.25	0.15	R
5454	–	–	–	–	0.03	1.0	0.02	–	–	–	R
5454-H32	0.162	*c*	*c*	0.10	0.75	2.7	0.13	–	0.25	0.20	R
BA28-1/4 H (5456)	0.050	0.18	0.32	0.036	0.26	5.08	<0.02	<0.02	0.05	–	R
5456-H321 + H343	0.125	*c*	*c*	0.10	0.75	5.0	0.13	–	0.25	0.20	R
5456-H321	–	–	–	0.15	0.7	5.0	0.15	–	–	–	R
5456-H327 + H343	–	0.10	0.16	0.10	0.80	5.0	0.07	–	0.01	0.05	R
5456-H34	–	0.10	0.30	0.08	0.77	5.0	0.07	–	–	–	R
5086	–	–	–	.	0.3	4.0	0.15	–	–	–	R
5086-H112	3 in. x 3 in. x 1/2 in. L	–	–	–	0.45	4.0	0.15	–	–	–	R
5086-H32	0.500	0.15	0.25	0.05	0.32	3.75	0.12	–	0.12	0.01	R
5086-H34	0.125	0.40	0.50	0.10	0.45	4.0	0.15	–	0.25	0.15	R
5086-H34	–	0.70	0.10	0.12	0.90	4.00	0.05	0.10	0.04	0.01	R

[a] R = remainder.

[b] Si + Fe = 0.23

[c] Si + Fe = 0.40

Table 70. Corrosion Rates and Types of Corrosion of 5000 Series Aluminum Alloys

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion				Source[c]
				Rate (mpy)	Maximum Pit Depth[b] (mils)	Crevice Depth[b] (mils)	Type[b]	
5050-H34	W	402	2,370	<0.1	4	0	P	REY (14)
5050-H34	W	402	2,370	0.1	I	31	C; I-P	CEL (4)
5050-H34	S	402	2,370	0.2	I	31	C; I-P	CEL (4)
5052-0	W	123	5,640	3.7	0	65	C (PR)	INCO (3)
5052-0	S	123	5,640	4.0	0	65	C (PR)	INCO (3)
5052-0	W	403	6,780	4.5	0	62	C (PR)	INCO (3)
5052-0	S	403	6,780	1.2	0	62	C (PR)	INCO (3)
5052-0	W	751	5,640	2.2	65	65	C (PR); P (PR)	INCO (3)
5052-0	S	751	5,640	3.2	0	62	C (PR)	INCO (3)
5052-0	W	1,064	5,300	3.1	0	65	C (PR)	INCO (3)
5052-0	S	1,064	5,300	1.5	0	62	C (PR)	INCO (3)
5052-0	W	197	2,340	1.8	0	65	C (PR)	INCO (3)
5052-0	S	197	2,340	<0.1	I	I	I-C; I-P	INCO (3)
5052-0	W	402	2,370	0.4	0	20	C	INCO (3)
5052-0	S	402	2,370	0.3	0	0	S-B at C	INCO (3)
5052-0	W	181	5	1.2	I	0	I-P	INCO (3)
5052-0	W	366	5	0.6	5	5	C; P	INCO (3)
5052-H22	W	1,064	5,300	0.4	–	–	–	CEL (4)
5052-H32	W	403	6,780	–	39	0	E-XF; P	NADC (7)
5052-H32	W	197	2,340	–	U	0	U-P	NADC (7)
5052-H32	S	197	2,340	<0.1	26	0	L-P	NADC (7)
5052-H32	W	402	2,370	–	F	0	E-XF; L; F-D-P	NADC (7)
5052-H34	W	123	5,640	<0.1	S	0	S-P	NADC (7)
5052-H34	W	123	5,640	–	PP	MO	MO-C; PP	Bell (13)
5052-H34	W	751	5,640	–	0	0	SH-CR	NADC (7)
5052-H34	W	751	5,640	–	SH	MO	MO-C; SH-P	Bell (13)
5052-H34	S	751	5,640	–	SH	S	S-C; SH-P	Bell (13)
5052-H34	W	197	2,340	<0.1	12	0	P	REY (14)
5052-H34	W	402	2,370	0.2	I	34	C; I-P	CEL (4)
5052-H34	S	402	2,370	0.2	I	50	C (PR); I-P	CEL (4)
5083-H113[d]	W	123	5,640	<0.1	28	0	P[e]	CEL (4)
5083-H113[d]	S	123	5,640	0.9	65	0	F-P	CEL (4)

Continued

Table 70. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion				Source[c]
				Rate (mpy)	Maximum Pit Depth[b] (mils)	Crevice Depth[b] (mils)	Type[b]	
5083-H113	W	189	5,900	0.1	I	30	C; I-P	CEL (4)
5083-H113[e]	W	189	5,900	0.1	4	3	SL-P	CEL (4)
5083-H113	S	189	5,900	0.3	20	11	C; P	CEL (4)
5083-H113[f]	S	189	5,900	0.2	4	I	I-C; SC-P[g]	CEL (4)
5083-H113	W	403	6,780	4.0	59	0	S-E; P	CEL (4)
5083-H113[d]	W	403	6,780	2.1	92	0	SL-E; P	CEL (4)
5083-H113	S	403	6,780	0.7	68	0	E; P	CEL (4)
5083-H113[d]	S	403	6,780	1.1	66	0	SL-E; P	CEL (4)
5083-H113[d]	W	751	5,640	1.6	83	0	E; P	CEL (4)
5083-H113	W	197	2,340	0.5	23	0	E; P[h]	CEL (4)
5083-H113[d]	W	197	2,340	0.3	57	0	P	CEL (4)
5083-H113	S	197	2,340	0.6	14	0	E; P[e]	CEL (4)
5083-H113[d]	S	197	2,340	0.7	55	0	P	CEL (4)
5083-H113	W	402	2,370	0.6	I	52	S-C; I-P	CEL (4)
5083	W	402	2,370	1.0	0	31	C	INCO (3)
5083-H113[d]	W	402	2,370	0.8	58	0	E; P	CEL (4)
5083-H113	S	402	2,370	0.6	I	57	S-C; I-P	CEL (4)
5083	S	402	2,370	0.4	17	0	P	INCO (3)
5083-H113[d]	S	402	2,370	0.8	48	0	E; S-P; WB (P)[i]	CEL (4)
5083-H113	W	181	5	1.2	I	3	C; IG (E); I-P	CEL (4)
5083	W	181	5	1.0	0	0	ET	INCO (3)
5083-H113[f]	W	181	5	0.9	0	0	ET	CEL (4)
5083	W	366	5	0.6	0	0	ET	INCO (3)
5083-H113	W	398	5	0.4	0	0	ET	CEL (4)
5083-H113[f]	W	398	5	0.5	34	I	I-C; P	CEL (4)
5083-H113	W	540	5	0.7	36	114	S-C; P	CEL (4)
5083-H113[f]	W	540	5	0.3	4	0	P	CEL (4)
5083-H113	W	588	5	0.3	11	I	I-C; P	CEL (4)
5083-H113[f]	W	588	5	0.3	9	0	P	CEL (4)
5086	W	402	2,370	0.8	0	35	C (PR)	INCO (3)
5086	S	402	2,370	0.7	0	35	C (PR)	INCO (3)
5086	W	181	5	1.2	I	0	I-P	INCO (3)
5086	W	366	5	0.5	5	5	C; P	INCO (3)

Continued

Table 70. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion				Source[c]
				Rate (mpy)	Maximum Pit Depth[b] (mils)	Crevice Depth[b] (mils)	Type[b]	
5086-H32	W	189	5,900	0.1	33	15	C; SC-P	CEL (4)
5086-H32	S	189	5,900	0.2	23	4	C; SC-P	CEL (4)
5086-H32[j]	W	360	4,200	0.1	47	0	E; P	CEL (4)
5086-H32[j]	S	360	4,200	<0.1	29	0	B; P	CEL (4)
5086-H32	W	197	2,340	<0.1	5	0	P	REY (14)
5086-H32	W	402	2,370	0.4	I	18	C; I-P	CEL (4)
5086-H32	S	402	2,370	0.5	I	18	C; I-P	CEL (4)
5086-H32	W	181	5	1.0	I	0	IG (E); I-P	CEL (4)
5086-H32	W	398	5	0.4	20	0	P	CEL (4)
5086-H32	W	588	5	0.2	22	I	I-C; P	CEL (4)
5086-H34	W	123	5,640	0.1	0	0	ET	CEL (4)
5086-H34[k]	W	123	5,640	–	–	–	NC-SD	NADC (7)
5086-H34	S	123	5,640	1.4	13	50	S-C; E; P	CEL (4)
5086-H34	W	189	5,900	0.2	3	0	SL-P	CEL (4)
5086-H34	S	189	5,900	0.7	55	126	C (PR); E; S-P	CEL (4)
5086-H34	W	403	6,780	0.6	I	53	S-C; I-P	CEL (4)
5086-H34	S	403	6,780	0.8	4	48	S-C; P	CEL (4)
5086-H34	W	751	5,640	2.0	72	60	S-C; E; S-P	CEL (4)
5086-H34[k]	W	751	5,640	–	PR	0	P (PR); L (HAZ&WB)	NADC (7)
5086-H34	W	1,064	5,300	0.9	73	69	S-C; S-E; S-P	CEL (4)
5086-H34	S	1,064	5,300	1.2	75	50	S-C; S-E; S-P[l]	CEL (4)
5086-H34[k]	W	360	4,200	<0.1	47	0	E; P	CEL (4)
5086-H34[k]	S	360	4,200	<0.1	51	0	E; P[m]	CEL (4)
5086-H34	W	197	2,340	0.7	29	I	I-C; SL-E; F-P	CEL (4)
5086-H34	S	197	2,340	1.1	53	38	S-C; S-E; S-P	CEL (4)
5086-H34	W	402	2,370	0.6	I	5	C; I-P	CEL (4)
5086-H34	S	402	2,370	1.3	17	48	S-C; P	CEL (4)
5086-H34	W	181	5	1.2	6	0	IG; P	CEL (4)
5086-H34	W	398	5	0.8	27	I	I-C; P	CEL (4)
5086-H34	W	540	5	0.3	0	I	I-C; ET	CEL (4)
5086-H34	W	588	5	1.6	47	43	S-C; S-P	CEL (4)
5086-H112[n]	S	189	5,900	0.1	21	32	C; SC-P	CEL (4)
5086-H112[n,j]	W	360	4,200	0.1	20	117	S-C; P	CEL (4)

Continued

Table 70. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion				Source[c]
				Rate (mpy)	Maximum Pit Depth[b] (mils)	Crevice Depth[b] (mils)	Type[b]	
5086-H112[n,j]	S	360	4,200	<0.1	20	64	S-C; P	CEL (4)
5086-H112[n]	W	181	5	1.1	I	0	I-P	CEL (4)
5454	W	402	2,370	0.4	0	28	C	INCO (3)
5454	S	402	2,370	0.6	0	80	C (PR)	INCO (3)
5454	W	181	5	1.0	I	0	I-P	INCO (3)
5454	W	366	5	0.5	0	0	ET	INCO (3)
5454-H32[d]	W	123	5,640	0.1	7	0	P[p]	CEL (4)
5454-H32[d]	S	123	5,640	1.1	49	0	E; S-P; SL (WB)	CEL (4)
5454-H32	W	403	6,780	0.9	38	0	MO-E; MO-P	CEL (4)
5454-H32[d]	W	403	6,780	1.7	64	0	E; P; L (HAZ)	CEL (4)
5454-H32	S	403	6,780	0.5	37	0	MO-E; MO-P	CEL (4)
5454-H32[d]	S	403	6,780	0.6	42	0	E; P; L (HAZ)	CEL (4)
5454-H32[d]	W	751	5,640	0.9	65	0	E; D-P; SL (WB)	CEL (4)
5454-H32	W	197	2,340	0.7	24	0	SL-E; P	CEL (4)
5454-H32[d]	W	197	2,340	0.3	41	0	MO-P; P (HAZ)	CEL (4)
5454-H32	S	197	2,340	0.6	16	0	SL-E; P	CEL (4)
5454-H32[d]	S	197	2,340	0.6	49	S	S-C; MO-P; P (HAZ)	CEL (4)
5454-H32	W	402	2,370	0.3	I	39	C; I-P	CEL (4)
5454-H32[d]	W	402	2,370	0.6	42	0	P; P (WB)[q]	CEL (4)
5454-H32	S	402	2,370	0.3	I	33	C; I-P	CEL (4)
5454-H32[d]	S	402	2,370	0.7	22	0	P[r]	CEL (4)
5454-H32[d]	W	398	5	0.5	8	0	P	CEL (4)
5454-H32[d]	W	540	5	0.3	I	0	I-P	CEL (4)
5454-H32[d]	W	588	5	0.7	39	0	P; P (WB&HAZ)	CEL (4)
BA28-1/4 H (5456)	W	197	2,340	<0.1	2	0	P	REY (14)
5456-H32	W	402	2,370	0.6	0	5	C; E	CEL (4)
5456-H32	S	402	2,370	0.7	0	21	C; E	CEL (4)
5456-H321	W	123	5,640	<0.1	0	SL	SL-C; SL-ET	CEL (4)
5456-H321	W	123	5,640	1.3	5	5	C; P	MEL (5)
5456-H321	S	123	5,640	2.1	49	33	C; E; S-P	CEL (4)
5456-H321	W	403	6,780	1.0	I	50	S-C; E; I-P	CEL (4)
5456-H321	S	403	6,780	0.8	44	32	C; E; F-P	CEL (4)

Continued

Table 70. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion				Source[c]
				Rate (mpy)	Maximum Pit Depth[b] (mils)	Crevice Depth[b] (mils)	Type[b]	
5456-H321	W	751	5,640	2.0	53	25	C; E; F-D-P	CEL (4)
5456-H321	W	751	5,640	2.2	17	23	C; EX-E; P	CEL (4)
5456-H321	S	751	5,640	2.2	50	45	S-C; E; F-D-P	CEL (4)
5456-H321	W	1,064	5,300	1.0	43	37	C; EX-E; F-D-P	CEL (4)
5456-H321	S	1,064	5,300	1.5	36	46	S-C; EX-E; F-P	CEL (4)
5456-H321	W	197	2,340	2.7	17	36	C; E; F-P	CEL (4)
5456-H321	S	197	2,340	2.6	43	18	C; E; F-D-P	CEL (4)
5456-H321	W	402	2,370	1.1	41	44	S-C; E; D-P	CEL (4)
5456-H321	S	402	2,370	1.2	14	32	C; E; P	CEL (4)
5456-H321	W	181	5	1.2	12	0	P	CEL (4)
5456-H321	W	398	5	0.6	16	0	P	CEL (4)
5456-H321	W	540	5	0.9	14	8	C; P	CEL (4)
5456-H34	W	123	5,640	–	31	0	CR (PR); S-E; P	NADC (7)
5456-H34	W	403	6,780	–	PR	0	P (PR); CR	NADC (7)
5456-H34	S	403	6,780	–	–	–	XF	NADC (7)
5456-H34	W	751	5,640	–	PR	–	CR; P (PR); XF; WB (C; S-CR; XF)	NADC (7)
5456-H34	W	1,064	5,300	–	32	PR	C (PR); P; S-XF	NADC (7)
5456-H34	W	1,064	5,300	–	63	I	I-C; E; D-P	CEL (4)
5456-H34	S	197	2,340	<0.1	12	S	S-C; CR (PR); E; P	NADC (7)
5456-H343	W	123	5,640	1.0	25	I	I-C; P	CEL (4)
5456-H343	W	123	5,640	–	S	0	S-E; CR (30); S-P	CEL (4)
5456-H343	W	403	6,780	0.2	I	28	C; I-P	CEL (4)
5456-H343	S	403	6,780	0.2	I	28	C; I-P	CEL (4)
5456-H343	W	751	5,640	1.1	0	64	C (PR); SL-E	CEL (4)
5456-H343	W	1,064	5,300	0.1	35	35	C; E; F-P	CEL (4)
5456-H343	W	197	2,340	0.4	0	I	I-C; E	CEL (4)
5456-H343	S	197	2,340	0.3	0	I	I-C; E	CEL (4)

[a]W = Totally exposed in seawater on sides of structure; S = Exposed in base of structure so that the lower portions of the specimens were embedded in the bottom sediments.

[b]Symbols for types of corrosion:

B	= Blisters	I	= Incipient	SC	= Scattered
C	= Crevice	IG	= Intergranular	SD	= Scattered discoloration
CR	= Crater	L	= Line	SH	= Shallow

Continued

Table 70. Continued.

D	= Deep	MO	= Moderate	SL	= Slight
E	= Edge	NC	= No visible corrosion	U	= Uniform
ET	= Etched	P	= Pitting	WB	= Weld bead
EX	= Extensive	PP	= Pin-point pitting	XF	= Exfoliated
F	= Few	PR	= Perforated		
HAZ	= Heat-affected zone	S	= Severe		

Numbers in parentheses indicate maximum depth in mils.

[c]Numbers refer to references at end of report.

[d]Welded with 5052 rod.

[e]Two measurable pits.

[f]Transverse butt weld, 5183 wire, MIG process.

[g]Scattered pitting, heavier in sediment than in water; shallow interconnected pitting in heat-affected zone parallel to weld bead.

[h]One measurable pit.

[i]Line of pits at edge of weld bead; 8 sq. in. area in bottom sediment reduced in thickness from 250 to 71 mils.

[j]Tongue-of-the Ocean, Atlantic Ocean, 4.5°C, 5.18 ml/l oxygen.

[k]Welded, 5566 rod, TIG process.

[l]6-sq.-in. area in sediment reduced in thickness by 60 mils.

[m]0.5-in.-wide undercut pits.

[n]3 x 3 x 1/2-in. angle

[p]Six measurable pits.

[q]Cracked in weld bead.

[r]4-sq-in. area in sediment reduced in thickness by 94 mils.

Table 71. Stress Corrosion of 5000 Series Aluminum Alloys

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed	Source[a]
5050-H34	11	50	402	2,370	3	0	CEL (4)
5050-H34	17	75	402	2,370	3	0	CEL (4)
5052-H32	8	30	403	6,780	3	0	NADC (7)
5052-H32	21	75	403	6,780	3	0	NADC (7)
5052-H32	8	30	197	2,340	3	0	NADC (7)
5052-H32	21	75	197	2,340	3	0	NADC (7)
5052-H32	8	30	402	2,370	3	0	NADC (7)
5052-H32	21	75	402	2,370	3	0	NADC (7)
5052-H34	15	50	402	2,370	3	0	CEL (4)
5052-H34	22	75	402	2,370	3	0	CEL (4)
5083-H113[b]	15	75	403	6,780	3	0	CEL (4)
5083-H113[b]	15	75	197	6,780	3	0	CEL (4)
5083-H113[b]	15	75	402	6,780	3	0	CEL (4)
5086-H32	15	50	402	2,370	3	0	CEL (4)
5086-H32	23	75	402	2,370	3	0	CEL (4)
5454-H32[b]	12	75	403	6,780	2	0	CEL (4)
5454-H32[b]	12	75	197	2,340	3	0	CEL (4)
5454-H32[b]	12	75	402	2,370	3	0	CEL (4)
5456-H32	20	50	402	2,370	3	0	CEL (4)
5456-H32	30	75	402	2,370	3	0	CEL (4)

[a]Numbers refer to references at end of report.

[b]Transverse butt weld with 5052 rod.

Table 72. Changes in Mechanical Properties of 5000 Series Aluminum Alloys Due to Corrosion

Alloy	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[a]
			Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
5050-H34	402	2,370	28	+2	22	+11	8	+25	CEL (4)
5052-H32	403	6,780	34	0	27	-4	11	-54	NADC (7)
5052-H32	197	2,340	34	-3	27	0	11	-3	NADC (7)
5052-H32	402	2,370	34	0	27	-4	11	-18	NADC (7)
5052-H34[b]	123	5,640	35	0	26	+3	11	+9	NADC (7)
5052-H34	751	5,640	34	-64	27	-58	11	+95	NADC (7)
5052-H34	402	2,370	37	+4	30	+7	9	+34	CEL (4)
5083-H113[c]	123	5,640	42	+4	20	-1	13	+26	CEL (4)
5083-H113	403	6,780	50	-15	38	-6	14	-30	CEL (4)
5083-H113[c]	403	6,780	42	+4	20	-5	13	+23	CEL (4)
5083-H113[c]	751	5,640	42	+5	20	-8	13	+32	CEL (4)
5083-H113	197	2,340	50	-1	38	-1	14	+3	CEL (4)
5083-H113[c]	197	2,340	42	+6	20	0	13	+21	CEL (4)
5083-H113	402	2,370	50	-1	38	0	14	+37	CEL (4)
5083-H113[c]	402	2,370	42	+2	20	-1	13	+17	CEL (4)
5083-H113	181	5	48	-2	35	-11	19	+16	CEL (4)
5083-H113[c]	181	5	41	+9	22	+11	13	+8	CEL (4)
5086-H32	402	2,370	44	-5	30	-6	14	+33	CEL (4)
5086-H32	181	5	46	-4	32	0	17	+41	CEL (4)
5086-H34[d,e]	123	5,640	49	-3	35	+8	13	-23	NADC (7)
5086-H34	123	5,640	48	-1	37	+2	12	-1	CEL (4)
5086-H34	403	6,780	48	0	37	-1	12	-5	CEL (4)
5086-H34	751	5,640	48	-7	37	-5	12	-9	CEL (4)
5086-H34	1,064	5,300	48	-2	37	-4	12	-3	CEL (4)
5086-H34	197	2,340	48	-5	37	-6	12	+4	CEL (4)
5086-H34	402	2,370	48	-3	37	-2	12	-3	CEL (4)
5086-H34	181	5	48	0	37	+2	12	-9	CEL (4)
5086-H112[f]	181	5	47	0	29	-3	16	-2	CEL (4)
5454-H32[c]	123	5,640	35	-1	16	+10	14	-11	CEL (4)
5454-H32	403	6,780	41	-2	31	-1	13	-22	CEL (4)
5454-H32[c]	403	6,780	35	-2	16	+23	14	-7	CEL (4)
5454-H32[c]	751	5,640	35	-16	16	+19	14	-36	CEL (4)
5454-H32	197	2,340	41	0	31	-1	13	-3	CEL (4)
5454-H32[c]	197	2,340	35	-3	16	-7	14	-3	CEL (4)
5454-H32	402	2,370	41	+4	31	+2	13	+27	CEL (4)
5454-H32	402	2,370	35	-4	16	+6	14	-6	CEL (4)
5456	402	2,370	50	-7	36	+1	15	-7	CEL (4)
5456-H321	123	5,640	56	-10	39	-5	14	-24	CEL (4)
5456-H321	403	6,780	56	-1	39	-6	14	+22	CEL (4)
5456-H321	751	5,640	56	-21	39	-33	14	-30	CEL (4)
5456-H321	1,064	5,300	56	-4	39	-8	14	-6	CEL (4)
5456-H321	197	2,340	56	-4	39	-10	14	0	CEL (4)
5456-H321	402	2,370	56	-1	39	-5	14	+9	CEL (4)
5456-H321	181	5	56	-1	39	-6	14	+9	CEL (4)

Continued

Table 72. Continued.

Alloy	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[a]
			Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
5456-H34	123	5,640	61	−6	43	+5	13	−34	NADC (7)
5456-H34	403	6,780	58	−14	50	−21	3	−80	NADC (7)
5456-H34	751	5,640	58	−14	50	−44	3	−71	NADC (7)
5456-H34	1,064	5,300	58	−14	50	−14	3	+94	NADC (7)
5456-H34	197	2,340	58	−14	50	−8	3	+170	NADC (7)
5454-H34[g]	403	6,780	58	−11	50	−14	3	+196	NADC (7)
5456-H343	123	5,640	34	+10	—	—	6	+33	NADC (7)
5456-H343	123	5,640	58	0	46	+2	9	+27	CEL (4)
5456-H343	403	6,780	58	−2	46	−6	9	+54	CEL (4)
5456-H343	751	5,640	58	−2	40	−1	9	+27	CEL (4)
5456-H343	1,064	5,300	58	−1	40	−3	9	+30	CEL (4)
5456-H343	197	2,340	58	−3	40	−1	9	+22	CEL (4)

[a]Numbers refer to references at end of report.

[b]Transverse properties.

[c]Transverse butt weld with 5052 rod.

[d]Transverse butt weld, 5566 electrode, TIG process.

[e]Mechanical properties transverse to direction of weld.

[f]3 in. x 3 in. x 1/2 in. angle.

[g]Anodized.

Table 73. Chemical Composition of 6000 Series Aluminum Alloys, Percent by Weight

Alloy	Gage (in.)	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Al[a]
6061		—	—	0.25	—	1.0	0.28	—	—	—	R
6061-T6	0.125	0.60	0.70	0.27	0.15	1.0	0.25	—	0.25	0.15	R
6061-T6	—	0.6	—	0.25	—	1.0	0.25	—	—	—	R
6061-T6	—	0.50	0.30	0.20	0.05	0.95	0.15	—	0.06	0.04	R

[a]R = remainder.

Table 74. Corrosion Rates and Types of Corrosion of 6000 Series Aluminum Alloys

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion				Source[c]
				Rate (mpy)	Maximum Pit Depth[b] (mils)	Crevice Depth[b] (mils)	Type[b]	
6061	W	402	2,370	1.2	0	32	C (PR)	INCO (3)
6061	S	402	2,370	0.7	0	32	C (PR)	INCO (3)
6061	W	181	5	1.2	5	0	P	INCO (3)
6061	W	366	5	0.9	11	11	C; P	INCO (3)
6061-T6	W	123	5,640	<0.1	5	10	C; P[d]	CEL (4)
6061-T6[e]	W	123	5,640	—	13	0	EX-IG; SC-P	NADC (7)
6061-T6[e,f]	W	123	5,640	—	SH	0	SH-P; WB&HAZ (B; EX-IG; P (30))	NADC (7)
6061-T6	W	123	5,640	5.2	27	21	C; P	MEL (5)
6061-T6[g]	W	123	5,640	—	—	—	F-PP	BELL (13)
6061-T6[h]	W	123	5,640	0	0	0	NC	BELL (13)
6061-T6	S	123	5,640	1.3	32	32	C; P	CEL (4)
6061-T6	W	189	5,900	0.1	3	0	SC-P	CEL (4)
6061-T6	S	189	5,900	0.1	33	18	C; SC-P[i]	CEL (4)
6061-T6	W	403	6,780	1.0	58	55	S-C; S-P	CEL (4)
6061-T6	W	403	6,780	—	—	—	MO-CR	NADC (7)
6061-T6	S	403	6,780	0.7	60	51	S-C; S-P	CEL (4)
6061-T6	W	751	5,640	1.1	65	65	S-C; E; S-P	CEL (4)
6061-T6[e]	W	751	5,640	—	—	—	CR (PR)	NADC (7)
6061-T6	W	751	5,640	2.6	63	63	C (PR); S-E; P (PR)	MEL (5)
6061-T6[g]	W	751	5,640	—	PR	0	P (PR); HAZ (PR)	BELL (13)
6061-T6[h]	W	751	5,640	—	PR	0	P (PR)	BELL (13)
6061-T6	S	751	5,640	1.6	72	75	S-C; E; S-P	CEL (4)
6061-T6	W	1,064	5,300	0.8	77	66	S-C; E; S-P	CEL (4)
6061-T6	S	1,064	5,300	1.0	77	0	E; S-P	CEL (4)
6061-T6	W	197	2,340	1.2	47	42	C; P	CEL (4)
6061-T6[e]	W	197	2,340	—	36	0	IG; P	NADC (7)
6061-T6	S	197	2,340	1.3	46	I	I-C; P	CEL (4)

Continued

Table 74. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion				Source[c]
				Rate (mpy)	Maximum Pit Depth[b] (mils)	Crevice Depth[b] (mils)	Type[b]	
6061-T6	W	402	2,370	2.0	75	66	S-C; S-P	CEL (4)
6061-T6	W	402	2,370	–	S	0	S-P	NADC (7)
6061-T6	S	402	2,370	1.2	76	60	S-C; S-P	CEL (4)
6061-T6	W	181	5	1.0	I	8	C; I-P	CEL (4)
6061-T6	W	398	5	0.7	16	0	E; P	CEL (4)
6061-T6	W	540	5	0.3	23	I	I-C; P	CEL (4)

[a] W = Totally exposed in seawater on sides of structure; S = Exposed in base of structure so that the lower portions of the specimens were embedded in the bottom sediments.

[b] Symbols for types of corrosion:

B	= Blisters	MO	= Moderate
C	= Crevice	NC	= No visible corrosion
CR	= Crater	P	= Pitting
E	= Edge	PR	= Perforated
EX	= Extensive	S	= Severe
F	= Few	SC	= Scattered
HAZ	= Heat-affected zone	SH	= Shallow
I	= Incipient	WB	= Weld Bead
IG	= Intergranular		

[c] Numbers refer to references at end of report.

[d] Six measurable pits.

[e] Welded, 6061 rod, TIG process.

[f] Re-heat treated after welding to T6 condition.

[g] Lap-welded, 4043 rod.

[h] Butt-welded, 4043 rod.

[i] Interconnected pits in portion in sediment.

Table 75. Stress Corrosion of 6000 Series Aluminum Alloys

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed	Source[a]
6061-T6	12	30	403	6,780	3	0	NADC (7)
6061-T6	30	75	403	6,780	3	0	NADC (7)
6061-T6	12	30	197	2,340	3	0	NADC (7)
6061-T6	30	75	197	2,340	3	0	NADC (7)
6061-T6	12	30	402	2,370	3	0	NADC (7)
6061-T6	30	75	402	2,370	3	0	NADC (7)

[a]Numbers refer to references at end of report.

Table 76. Changes in Mechanical Properties of 6000 Series Aluminum Alloys Due to Corrosion

Alloy	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[a]
			Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
6061-T6	123	5,640	48	-7	41	-2	17	-58	CEL (4)
6061-T6[b]	123	5,640	44	-43	38	-43	12	-85	NADC (7)
6061-T6[b,c]	123	5,640	44	-100	38	-100	12	-100	NADC (7)
6061-T6	403	6,780	48	-11	41	-19	17	-58	CEL (4)
6061-T6	751	5,640	48	-24	41	-41	17	-73	CEL (4)
6061-T6	1,064	5,300	48	-11	41	-9	17	-61	CEL (4)
6061-T6	197	2,340	48	-5	41	0	17	-42	CEL (4)
6061-T6	197	2,340	44	-2	38	+3	12	-57	NADC (7)
6061-T6	402	2,370	48	-15	41	-9	17	-70	CEL (4)
6061-T6	181	5	48	0	41	+2	17	-9	CEL (4)

[a]Numbers refer to references at end of report.

[b]Transverse butt weld, 6061 electrode, TIG process.

[c]Transverse welds excessively corroded; not possible to obtain tensile specimens.

Table 77. Chemical Composition of 7000 Series Aluminum Alloys, Percent by Weight

Alloy	Gage (in.)	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Al[a]
7002-T6	0.063	0.11	0.17	0.78	0.17	2.73	0.19	<0.02	3.76	0.04	R
X7002-T6	0.063	0.20	0.40	0.75	0.15	2.50	0.15	–	3.5		R
7002-T6	–	0.40	0.15	1.00	0.17	2.30	0.20	–	3.80	0.02	R
Alclad 7002-T6	0.063										
Core (7002)		–	–	0.75	0.18	2.5	0.20	–	3.5	–	R
Cladding (7072)		–	–	–	–	–	–	–	1.0	–	R
7039-T6	0.250	0.11	0.17	–	0.22	2.8	0.21	–	4.0	0.02	R
7039-T64	0.500	0.30	0.40	0.10	0.25	2.8	0.20	–	4.0	0.10	R
7-75-T6, T6A	–	0.10	0.14	1.40	0.08	2.10	0.30	–	5.10	0.07	R
7075-T73	–	0.10	0.14	1.20	0.02	2.20	0.20	–	5.10	0.02	R
Alclad 7075-0											
Core (7075)		0.17	0.25	1.53	0.06	2.45	0.22	–	5.65	0.03	R
Cladding (7072)		*b*	*b*	0.05	<0.01	0.10	0.03	–	1.34	–	R
7079-T6	0.063	0.14	0.12	0.64	0.20	3.50	0.16	–	4.3	0.03	R
7079-T6	–	–	–	0.6	0.2	3.3	0.2	–	4.3	–	R
Alclad 7079-T6	0.063										
Core (7079)		–	–	0.6	0.2	3.3	0.17	–	4.3	–	R
Cladding (7072)		–	–	–	–	–	–	–	1.0	–	R
7106-W51[c]											
7178-0	–	0.19	0.15	1.73	0.05	2.50	0.19	–	6.31	0.04	R
7178-T6	0.064	0.50	0.70	2.0	0.03	2.75	0.3	–	6.8	0.10	R
7178-T6	0.050	0.12	0.25	1.75	0.02	2.44	0.25	–	6.67	0.06	R
7178-T6	–	0.10	0.20	1.00	0.05	2.50	0.18	–	7.10	0.03	R
XAP001-T6[d]											

[a] R = remainder.
[b] Si + Fe = 0.39.
[c] No analysis given.
[d] Experimental metal compact.

Table 78. Corrosion Rates and Types of Corrosion of 7000 Series Aluminum Alloys

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion				Source[c]
				Rate (mpy)	Maximum Pit Depth[b] (mils)	Crevice Depth[b] (mils)	Type[b]	
7002-T6	W	123	5,640	–	13	0	E; IG; SH-P; XF	NADC (7)
7002-T6, welded[d]	W	123	5,640		PR	0	S-E; MO-IG; SH-P; WB (PR); XF	NADC (7)
7002-T6[d,e]	W	123	5,640	–	PR	0	E; IG; SH-P; WB (PR); XF	NADC (7)
7002-T6	W	403	6,780	1.2	62	0	E; P (PR)	CEL (4)
7002-T6	W	403	6,780		I	0	I-P	NADC (7)
7002-T6	S	403	6,780	3.2	62	0	E; P (PR)	CEL (4)
7002-T6	W	751	5,640	–	0	0	NC	NADC (7)
7002-T6, anodized	W	751	5,640	–	0	0	E	NADC (7)
7002-T6, welded[d]	W	751	5,640	–	0	0	WB (HC)	NADC (7)
7002-T6, welded[d]	W	197	2,340	–	0	0	E; IG; U; WB (S; IG)	NADC (7)
7002-T6	W	197	2,340	<0.1	15	0	P; XF	REY (14)
7002-T6	W	197	2,340	<0.1	0	0	NC	Boeing (6)
7002-T6	W	402	2,370	1.6	30	62	C (PR); P	CEL (4)
7002-T6, welded[d]	W	402	2,370	–	SH	0	E; SH-P; WB&HAZ (S)	NADC (7)
7002-T6	S	402	2,370	1.9	5	62	C (PR); P[f]	CEL (4)
Alclad 7002-T6	W	403	6,780	1.4	5	0	P[g]	CEL (4)
Alclad 7002-T6	W	403	6,780		0	0	G	NADC (7)
Alclad 7002-T6	W	403	6,780	0.2	4	0	P[h]	CEL (4)
Alclad 7002-T6	W	751	5,640	–	0	0	G	NADC (7)
Alclad 7002-T6	W	197	2,340	<0.1	6	0	P[i]	REY (14)
Alclad 7002-T6	W	402	2,370	0.8	5	5	C; P	CEL (4)
Alclad 7002-T6	W	402	2,370	–	0	0	SL-B	NADC (7)
Alclad 7002-T6	S	402	2,370	1.0	5	5	C; P[j]	CEL (4)
7106	W	197	2,340	<0.1	0	0	NC	Boeing (6)
X7106-W51, welded[k]	W	197	2,340	-			NC	Boeing (6)
7039-T6	W	123	5,640	0.7	3	0	P; XF	CEL (4)
7039-T6	S	123	5,640	2.1	38	2	C; P; XF	CEL (4)
7039-T6	W	403	6,780	–	–	–	EX-XF	CEL (4)
7039-T6	S	403	6,780	–	–	–	EX-XF	CEL (4)
7039-T6	W	751	5,640			–	EX-XF	CEL (4)
7039-T6	S	751	5,640	–	–		EX-XF	CEL (4)
7039-T6	W	197	2,340	1.9	27	0	P; XF	CEL (4)

Continued

Table 78. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion				Source[c]
				Rate (mpy)	Maximum Pit Depth[b] (mils)	Crevice Depth[b] (mils)	Type[b]	
7039	W	197	2,340	<0.1	0	0	NC	Boeing (6)
7039-T6	S	197	2,340	1.2	61	0	D-P; XF	CEL (4)
7039-T6	W	402	2,370	–	–	–	EX-XF	CEL (4)
7039-T6	S	402	2,370	–	–	–	EX-XF	CEL (4)
7039-T64	W	189	5,900	0.2	1	14	C; I-P	CEL (4)
7039-T64, welded[l]	W	189	5,900	0.3	41	1	I-C; P; L (HAZ)	CEL (4)
7039-T64	S	189	5,900	0.3	40	45	C; SC-P	CEL (4)
7039-T64, welded[l]	S	189	5,900	0.3	47	1	I-C; P; P (HAZ)	CEL (4)
7039-T64	W	181	5	1.1	0	0	ET	CEL (4)
7039-T64, welded[l]	W	181	5	1.2	1	0	I-P	CEL (4)
7039-T64	W	398	5	1.1	22	1	I-C; P	CEL (4)
7039-T64, welded[l]	W	398	5	0.5	0	0	P (WB&HAZ)	CEL (4)
7039-T64	W	540	5	0.3	6	3	C; P	CEL (4)
7039-T64, welded[l]	W	540	5	0.3	18	1	I-C; P (HAZ)	CEL (4)
7039-T64, welded[l]	W	588	5	0.3	26	1	I-C; P (HAZ)	CEL (4)
7075-T6	W	123	5,640	–	8	0	E; IG; L; G-P	NADC (7)
7075-T6	W	403	6,780	–	PR	0	P (PR)	NADC (7)
7075-T6	S	403	6,780	–	PR	0	P (PR)	NADC (7)
7075-T6A	W	403	6,780	–	PR	0	P (PR); XF (E)	NADC (7)
7075-T6	W	751	5,640	–	PR	–	C; P (PR); XF (E)	NADC (7)
7075-T6A	W	751	5,640	–	PR	0	P (PR); XF (E)	NADC (7)
7075-T6	W	1,064	5,300	–	PR	0	P (PR); S-XF (E)	NADC (7)
7075-T6A	W	1,064	5,300	–	PR	0	P (PR); XF (E)	NADC (7)
7075-T6	W	197	2,340	–	31	–	C; IG; P; S-XF (E)	NADC (7)
7075-T6	S	197	2,340	–	SL	–	C; IG; SL-P; XF (E)	NADC (7)
7075-T6A	W	197	2,340	–	44	0	SL-IG; SC-P	NADC (7)
7075-T6A	S	197	2,340	–	44	0	SL-IG; N-P	NADC (7)
7075-T6	W	402	2,370	–	SL	0	S-E; SL-P	NADC (7)
7075-T6	S	402	2,370	–	SL	0	S-E; SL-P	NADC (7)
7075-T6A	W	402	2,370	–	PR	0	P (PR)	NADC (7)
7075-T6A	S	402	2,370	–	PR	0	P (PR)	NADC (7)

Continued

Table 78. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion				Source[c]
				Rate (mpy)	Maximum Pit Depth[b] (mils)	Crevice Depth[b] (mils)	Type[b]	
7075-T64	W	123	5,640	–	40	0	EX-P	NADC (7)
7075-T73	W	123	5,640	–	20	0	SC-P	NADC (7)
7075-T73	W	403	6,780	–	SH	0	SH-P; SL-XF (E)	NADC (7)
7075-T73	S	403	6,780	–	SH	0	SH-P; SL-XF (E)	NADC (7)
7075-T73	W	751	5,640	–	PR	0	P (PR)	NADC (7)
7075-T73	W	197	2,340	–	0	–	C; E; SL-IG	NADC (7)
7075-T73	W	402	2,370	–	31	0	B (E); P; XF(E)	NADC (7)
7075-T73	S	402	2,370	–	0	0	B	NADC (7)
Alclad 7075-0	W	1,064	5,300	–	–	–	U	CEL (4)
Alclad 7075-T6	W	123	5,640	–	–	–	B; I-IG	NADC (7)
7079-T6	W	123	5,640	5.2	79	36	C; E; P (PR); XF	CEL (4)
7079-T6	W	123	5,640	0.7	4	9	C; P	MEL (5)
7079-T6	S	123	5,640	3.0	77	32	C; E; P (PR); XF	CEL (4)
7079-T6	W	403	6,780	5.1	77	36	C; S-E; P (PR)	CEL (4)
7079-T6	S	403	6,780	3.4	57	38	C; S-E; P	CEL (4)
7079-T6	W	751	5,640	2.8	79	79	C (PR); P (PR); XF	CEL (4)
7079-T6	W	751	5,640	2.2	41	80	S-C; P	MEL (5)
7079-T6	S	751	5,640	2.7	77	77	C (PR); P (PR); XF	CEL (4)
7079-T6	W	197	2,340	4.7	77	46	C; E; P (PR); XF	CEL (4)
7079-T6	S	197	2,340	3.0	49	55	C; E; P; XF	CEL (4)
7079-T6	W	402	2,370	1.6	16	35	C; S-E; P	CEL (4)
7079-T6	S	402	2,370	1.4	21	27	C; S-E; P	CEL (4)
Alclad 7079-T6	W	197	2,340	<0.1	3	0	P[m]	REY (14)
7178-T6	W	123	5,640	4.1	43	0	P; XF	CEL (4)
7178-T6	W	123	5,640	–	63	0	P (PR); S-IG	NADC (7)
7178-T6	W	403	6,780	4.9	15	35	C; S-E; P; XF	CEL (4)
7178-T6	W	403	6,780	–	PR	0	S-E; P (PR)	NADC (7)
7178-T6	S	403	6,780	4.4	25	30	C; S-E; P; XF	CEL (4)
7178-T6	W	751	5,640	1.5	36	30	C; S-E; P; XF	CEL (4)
7178-T6	W	751	5,640	–	PR	0	S-E; P (PR)	NADC (7)
7178-T6	W	1,064	5,300	1.4	45	39	C; S-E; P; XF	CEL (4)

Continued

Table 78. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion				Source[c]
				Rate (mpy)	Maximum Pit Depth[b] (mils)	Crevice Depth[b] (mils)	Type[b]	
7178-T6	W	197	2,340	3.2	0	–	C; XF	CEL (4)
7178-T6	W	197	2,340	0.2	50	0	P (PR)	REY (14)
7178-T6	W	197	2,340	–	31	–	C; IG; P; S-XF (E)	NADC (7)
7178-T6	S	197	2,340	–	SL	–	C; IG; SL-P; XF (E)	NADC (7)
7178-T6	S	197	2,340	2.4	0	–	C; XF	CEL (4)
7178-T6	W	402	2,370	3.3	34	34	C; E; P; XF	CEL (4)
7178-T6	W	402	2,370	–	82	0	S-E; P (PR)	NADC (7)
7178-T6	S	402	2,370	–	–	0	E; P	NADC (7)
7178-T6	S	402	2,370	1.8	31	34	C; E; P; XF	CEL (4)
Alclad 7178-T6	W	751	5,640	–	PR	0	P (PR)	NADC (7)

[a]W = Totally exposed in seawater on sides of structure; S= Exposed in base of structure so that the lower portions of the specimens were embedded in the bottom sediments.

[b]Symbols for types of corrosion:

B	= Blisters	HC	= Honeycomb	PR	= Perforated
C	= Crevice	I	= Incipient	S	= Severe
D	= Deep	IG	= Intergranular	SC	= Scattered
E	= Edge	L	= Line	SH	= Shallow
ET	= Etched	MO	= Moderate	SL	= Slight
EX	= Extensive	N	= Numerous	U	= Uniform
G	= General	NC	= No visible corrosion	WB	= Weld Bead
HAZ	= Heat-affected zone	P	= Pitting	XF	= Exfoliated (delaminated)

[c]Numbers refer to references at end of report.

[d]Transverse butt weld, MRD 7-5 electrode, TIG process.

[e]Reheat treated to T6 condition after welding.

[f]Part of one specimen missing.

[g]80% of cladding gone.

[h]10% of cladding gone.

[i]3.1-mil-thick cladding.

[j]15% of cladding gone.

[k]Welded by the TIG process and aged.

[l]Transverse butt welded, 7039 wire, MIG process.

[m]2.6-mil-thick cladding.

Table 79. Stress Corrosion of 7000 Series Aluminum Alloys

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed	Source[a]
7002-T6	18	30	403	6,780	3	0	NADC (7)
7002-T6	45	75	403	6,780	3	0	NADC (7)
7002-T6	18	30	402	2,370	3	0	NADC (7)
7002-T6	30	50	402	2,370	3	0	CEL (4)
7002-T6	45	75	402	2,370	3	0	NADC (7)
7002-T6	45	75	402	2,370	3	0	CEL (4)
Alclad 7002-T6	18	30	403	6,780	3	0	NADC (7)
Alclad 7002-T6	45	75	403	6,780	3	0	NADC (7)
Alclad 7002-T6	18	30	402	2,370	3	0	NADC (7)
Alclad 7002-T6	29	50	402	2,370	3	0	CEL (4)
Alclad 7002-T6	45	75	402	2,370	3	0	NADC (7)
Alclad 7002-T6	43	75	402	2,370	3	0	CEL (4)
7075-T6	22	30	403	6,780	3	1	NADC (7)
7075-T6	55	75	403	6,780	3	*b*	NADC (7)
7075-T6	22	30	197	2,340	3	0	NADC (7)
7075-T6	55	75	197	2,340	3	2	NADC (7)
7075-T6	22	30	402	2,370	3	0	NADC (7)
7075-T6	55	75	402	2,370	3	2	NADC (7)
7075-T6A[c]	12	30	403	6,780	3	*b*	NADC (7)
7075-T6A[c]	30	75	403	6,780	3	*b*	NADC (7)
7075-T6A[c]	12	30	197	2,340	3	0	NADC (7)
7075-T6A[c]	30	75	197	2,340	3	0	NADC (7)
7075-T6A[c]	12	30	402	2,370	3	0	NADC (7)
7075-T6A[c]	30	75	402	2,370	3	0	NADC (7)
7075-T73	24	30	403	6,780	3	0	NADC (7)
7075-T73	51	75	403	6,780	3	0	NADC (7)
7075-T73	24	30	197	2,340	3	0	NADC (7)
7075-T73	51	75	197	2,340	3	0	NADC (7)
7075-T73	24	30	402	2,370	3	0	NADC (7)
7075-T73	51	75	402	2,370	3	0	NADC (7)
7079-T6	34	50	402	2,370	3	2	CEL (4)
7079-T6	50	75	402	2,370	3	3	CEL (4)
Alclad 7079-T6	35	50	402	2,370	3	1	CEL (4)
Alclad 7079-T6	53	75	402	2,370	3	2	CEL (4)
7178-T6	19	30	403	6,780	3	0	NADC (7)
7178-T6	49	75	403	6,780	3	*b*	NADC (7)
7178-T6	19	30	197	2,340	3	0	NADC (7)
7178-T6	49	75	197	2,340	3	0	NADC (7)
7178-T6	19	30	402	2,370	3	0	NADC (7)
7178-T6	41	50	402	2,370	3	0	CEL (4)
7178-T6	49	75	402	2,370	3	3	NADC (7)
7178-T6	61	75	402	2,370	3	3	CEL (4)
XAP001-T6	6	30	403	6,780	3	*b*	NADC (7)
XAP001-T6	15	75	403	6,780	3	0	NADC (7)

[a] Numbers refer to references at end of report.

[b] Missing when STU was recovered.

[c] Alloy 7076-T6 heated 8 hours at 350°F, air cooled.

Table 80. Changes in Mechanical Properties of 7000 Series Aluminum Alloys Due to Corrosion

Alloy	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[a]
			Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
7002-T6	123	5,640	76	-10	68	-12	12	-8	NADC (7)
7002-T6[b]	123	5,640	33	-32	—	—	2	-100	NADC (7)
7002-T6[b,c,d]	123	5,640	—	-100	—	-100	—	-100	NADC (7)
7002-T6	403	6,780	70	-62	58	-71	14	-91	CEL (4)
7002-T6	403	6,780	76	-12	68	-15	12	-8	NADC (7)
7002-T6	751	5,640	76	-8	68	-12	12	+17	NADC (7)
7002-T6[b,d]	197	2,340	—	-100	—	-100	—	-100	NADC (7)
7002-T6	402	2,370	70	-1	58	0	14	0	CEL (4)
7002-T6	402	2,370	76	-10	68	-16	12	-14	NADC (7)
Alclad 7002-T6	403	6,780	65	-1	54	+3	15	-14	CEL (4)
Alclad 7002-T6	402	2,370	65	-3	54	0	15	-10	CEL (4)
7039-T6	123	5,640	69	-4	60	-3	14	-16	CEL (4)
7039-T6[d]	403	6,780	69	-100	60	-100	14	-100	CEL (4)
7039-T6[d]	751	5,640	69	-100	60	-100	14	-100	CEL (4)
7039-T6	197	2,340	69	-2	60	-2	14	-2	CEL (4)
7039-T6[d]	402	2,370	69	-100	60	-100	14	-100	CEL (4)
7039-T64	181	5	63	+2	53	+6	16	+13	CEL (4)
7039-T64[e]	181	5	63	+17	53	+4	16	+67	CEL (4)
7075-T6	123	5,640	83	0	76	+1	11	-5	NADC (7)
7075-T6	403	6,780	83	-37	76	-28	11	-94	NADC (7)
7075-T6	751	5,640	83	-13	76	-9	11	-84	NADC (7)
7075-T6	1,064	5,300	83	-13	76	-10	11	-52	NADC (7)
7075-T6	197	2,340	83	-8	76	-4	11	-55	NADC (7)
7075-T6	402	2,370	83	-20	76	—	11	-91	NADC (7)
7075-T6A[f]	197	2,340	71	-22	61	-18	10	-10	NADC (7)
7075-T6A[f]	402	2,370	71	+7	61	-10	10	-20	NADC (7)
7075-T64	123	5,640	71	-41	61	-31	10	-100	NADC (7)
7075-T73	123	5,640	72	0	62	0	10	+10	NADC (7)
7075-T73	403	6,780	72	-11	62	-3	10	-75	NADC (7)
7075-T73	751	5,640	72	-8	62	-8	10	0	NADC (7)
7075-T73	197	2,340	72	-3	62	0	10	+10	NADC (7)
7075-T73	402	2,370	72	0	62	+9	10	-70	NADC (7)
Alclad 7075-T6	123	5,640	76	0	68	0	10	-10	NADC (7)
7079-T6	123	5,640	76	-66	67	-63	11	-74	CEL (4)
7079-T6	403	6,780	76	-43	67	-52	11	-70	CEL (4)
7079-T6[d]	751	5,640	76	-100	67	-100	11	-100	CEL (4)
7079-T6	197	2,340	76	-17	67	-4	11	-23	CEL (4)
7079-T6	402	2,370	76	-1	67	0	11	-22	CEL (4)
Alclad 7079-T6	402	2,370	78	-2	69	-1	12	+4	CEL (4)
7178-T6	123	5,640	88	-19	80	-16	10	-16	CEL (4)
7178-T6[g]	123	5,640	89	-49	65	—	11	-91	NADC (7)
7178-T6	403	6,780	88	-41	80	-41	10	-82	CEL (4)
7178-T6	403	6,780	89	-56	65	—	11	-91	NADC (7)

Continued

Table 80. Continued.

Alloy	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[a]
			Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
7178-T6	751	5,640	88	-48	80	-64	10	-58	CEL (4)
7178-T6	751	5,640	89	-90	65	–	11	-91	NADC (7)
7178-T6	1,064	5,300	88	-4	80	-33	10	+12	CEL (4)
7178-T6	197	2,340	88	-19	80	-37	10	-52	CEL (4)
7178-T6	197	2,340	89	-17	65	0	11	-10	NADC (7)
7178-T6	402	2,370	88	-24	80	-21	10	-80	CEL (4)
7178-T6	402	2,370	89	-58	65	–	11	-100	NADC (7)

[a]Numbers refer to references at end of report.

[b]Welded, MDR 7-5 electrode, TIG process.

[c]Reheat treated to T6 condition after welding.

[d]Specimens too corroded (exfoliated) to machine into tensile specimens.

[e]Transverse butt weld, 7039 wire, MIG process.

[f]Alloy 7075-T6 heated for 8 hours at 350°F, air cooled.

[g]Properties transverse to the direction of rolling.

SECTION 7

TITANIUM ALLOYS

Titanium and titanium alloys owe their corrosion resistance to a protective oxide film. This film resists attack by oxidizing solutions, in particular those containing chloride ions. It has outstanding resistance to corrosion and pitting in marine environments and other chloride salt solutions.

The chemical compositions of the titanium alloys are given in Table 81, their corrosion rates and types of corrosion in Table 82, their susceptibility to stress corrosion in Table 83, and the effects of exposure on their mechanical properties in Table 84.

7.1. CORROSION

The corrosion rates and type of corrosion of the titanium alloys are given in Table 82.

Except for two alloys, there was no corrosion of any of the titanium alloys during exposures in surface seawater or at depths of 2,500 and 6,000 feet. Reference 15 reported a corrosion rate of 0.19 mpy for unalloyed titanium and of 0.18 mpy for 6Al-4V after 123 days of exposure at the 6,000-foot depth, but no corrosion of these same alloys after 751 days of exposure at the 6,000-foot depth. Also, no visible corrosion was reported. For practical purposes these values are considered to be inconsequential. DeLuccia, Reference 17, reported cracking in the heat-affected zone parallel to the weld bead in alloy 6Al-4V after 197 days of exposure at the 2,500-foot depth. Investigation of the weldments showed that the welds had been made under improper conditions and were contaminated with oxygen which made them brittle.

Alloys 75A, 0.15Pd, 5Al-2.5Sn, 6Al-4V, 7Al-2Cb-1Ta, 6Al-2Cb-1Ta-1Mo, and 13V-11Cr-3Al were both unwelded and welded. They were fusion-welded by the inert-gas shielded arc, nonconsumable tungsten electrode process (TIG). There were transverse butt welds across the 6-inch dimension of the specimens and 3-inch-diameter ring welds in the centers of 6 x 12-inch specimens. The welded specimens were intentionally not stress relieved in order to simulate the conditions present in a welded structure, i.e., to retain the maximum residual internal welding stresses. The process of placing a circular weld in a specimen imposes very high residual stresses in the specimen. Such circular welds simulate multiaxial stresses imposed in structures or parts fabricated by welding. There was no visible corrosion of these welded alloys except for stress corrosion cracking of alloy 13V-11Cr-3Al. This will be discussed under 7.2.

Alloy 6Al-4V was also exposed as:

(1) Wire, 0.020- 0.045-, and 0.063-inch diameter.

(2) Cables, 1/16-inch (1 x 19), 1/4-inch (6 x 19), 1/4-inch (6 x 19) with Type 304 stainless steel swaged ends, and 1/4-inch (6 x 19) with ends tied with mild steel wire.

(3) Flash-welded tube.

(4) Flash-welded sphere.

(5) Piece from broken sphere.

(6) Welded rings 9.625-inch OD x 1.125-inch wide x 8.75-inch ID. One ring was unstressed and the others were stressed up to a maximum of 60,000 psi.

There was no visible corrosion on any of the above specimens except for the AISI Type 304 swaged fittings and the mild steel wire. The faying surfaces of the Type 304 stainless steel fittings were severely attacked by crevice corrosion. The rate of this crevice corrosion was probably increased by the galvanic couple formed by the two dissimilar metals, with the stainless steel being the anode of the couple. The mild steel wire used to tie the end of one titanium cable was corroded almost through by galvanic corrosion; the mild steel wire was anodic to the titanium cable.

7.2. STRESS CORROSION

Specimens of the alloys were stressed in various ways and to values equivalent to 30, 35, 50, and 75%

of their respective yield strengths at the surface and at depths of 2,500 and 6,000 feet for different periods of time.

The majority of the specimens were deformed by bowing to obtain the desired tensile stress in the central 2-inch length of the outer surface of the specimen. Many of these specimens, butt-welded by the TIG process, were positioned such that the transverse weld bead was at the apex of the bow in the 2-inch length. Other specimens, 6 x 12-inch, had a 3-inch-diameter circular weld bead placed in the center. The stresses induced by the welding operation were not relieved in order to retain the maximum residual stresses in the specimens. Still other specimens were in the shape of welded rings, 9-5/8 inches outside diameter, which were deformed different amounts in order to induce tensile stresses in the periphery at the ends of the restraining rods.

The results of the stress corrosion tests are given in Table 83. There were no stress corrosion cracking failures of any of the alloys, both unwelded and butt-welded, stressed at values equivalent to as high as 75% of their respective yield strengths for 180 days of exposure at the surface, 402 days at the 2,500-foot depth, and 751 days at the 6,000-foot depth, except for the butt-welded 13V-11Cr-3Al alloy. The unrelieved butt-welded 13V-11Cr-3A1 alloy failed by stress corrosion cracking when stressed at values equivalent to 75% (94,500 psi) of its yield strength after 35, 77, and 105 days of exposure at the surface in the Pacific Ocean. The stress corrosion cracks were in the heat-affected zones at the edges of and parallel to the weld beads.

The butt-welded 6 x 12-inch specimens of 13-V-11Cr-3Al alloy failed by stress corrosion during 398, 540, and 588 days of exposure at the surface due to the unrelieved residual welding stresses. The stress corrosion cracks were perpendicular to and extended across the weld beads from side to side.

The 6Al-4V alloy rings stressed as high as 60,000 psi (approximately 50% of its yield strength) did not fail by stress corrosion cracking during 402 days of exposure at the 2,500-foot depth.

Alloys 75A, 0.15Pd, 5Al-2.5Sn, 7Al-2Cb-1Ta, 6Al-2Cb-1Ta-1Mo, 6Al-4V, and 13V-11Cr-3Al were exposed with an unrelieved 3-inch-diameter circular weld bead in the center of 6 x 12-inch specimens. Only the 13V-11Cr-3Al alloy failed by stress corrosion cracking because of the residual welding stresses. Failure by stress corrosion cracking occurred first after 181 days of exposure at the surface. Thereafter, failures first occurred during 189 days of exposure when partially embedded in the bottom sediments and during 751 days of exposure in the seawater at the 6,000-foot depth. At the 2,500-foot depth the first failure occurred during 402 days of exposure in the seawater. The cracks in all cases extended radially across the weld beads. In some cases, the cracks changed direction by 90% and propagated circumferentially around the outside of the weld bead. In general, the 13V-11Cr-3Al alloy was more susceptible to stress corrosion cracking in seawater at the surface than at depth in the Pacific Ocean.

7.3. MECHANICAL PROPERTIES

The effects of exposure in seawater on the mechanical properties of the titanium alloys are given in Table 84. The mechanical properties of the titanium alloys were not adversely affected.

Table 81. Chemical Composition of Titanium Alloys

Alloy	C	Fe	N	H	O	Al	V	Cr	Other	Ti[a]	Source[a]
Titanium	<0.1	–	0.02	–	–	–	–	–	–	R	INCO (3)
75A	0.027	0.20	0.026	0.004	–	–	–	–	–	R	CEL (4)
75A	0.025	0.13	0.016	0.003	0.28	–	–	–	–	R	CEL (4)
75A	0.025	0.14	0.017	0.003	0.32	–	–	–	–	R	CEL (4)
0.15Pd	0.022	0.06	0.009	0.003	0.15	–	–	–	0.15 Pd	R	CEL (4)
0.15Pd	0.022	0.05	0.012	0.004	–	–	–	–	0.15 Pd	R	CEL (4)
5Al-2.5Sn	0.025	0.34	0.014	0.011	–	5.1	–	–	2.2 Sn	R	CEL (4)
5Al-2.5Sn	0.022	0.27	0.013	0.006	0.18	5.1	–	–	2.4 Sn	R	CEL (4)
5Al-2.5 Sn	0.025	0.35	0.013	0.008	0.17	5.1	–	–	2.5 Sn	R	CEL (4)
7Al-2Cb-1Ta	0.023	0.06	0.006	0.002	0.07	7.0	–	–	1.0 Ta	R	CEL (4)
4Al-3Mo-1V	–	–	–	–	–	4.30	0.95	–	2.91 Mo	R	NADC (7)
4Al-3Mo-1V[c]	0.08	0.25	0.05	0.15	–	4.25	1.0	–	3.0 Mo	R	CEL (4)
4Al-3Mo-1V	–	0.1	–	–	–	4.5	0.9	0.2	3.7 Mo	R	CEL (4)
8Mn[c]	0.20	–	0.07	0.15	–	–	–	–	8.0 Mn	R	CEL (4)
140A	–	1.9	–	–	–	<0.1	< 0.1	2.1	1.9 Mo	R	CEL (4)
6Al-4V	–	–	–	–	–	5.61	4.13	–	–	R	NADC (7)
6Al-4V	0.023	0.15	0.015	0.007	–	6.0	3.9	–	–	R	CEL (4)
6Al-4V	0.025	0.13	0.015	0.007	–	5.9	4.0	–	–	R	CEL (4)
6Al-4V	0.022	0.08	0.013	0.007	0.11	5.8	4.0	–	–	R	CEL (4)
6Al-4V	–	0.1	–	–	–	7.2	5.2	< 0.1	–	R	CEL (4)
7Al-12Zr	–	–	–	–	–	5.93	–	–	11.27 Zr	R	NADC (7)
6Al-2Cb-1Ta-1Mo	0.02	0.06	0.006	0.002	0.077	6.1	–	–	2.2 Cb 1.1 Ta 0.74 Mo	R	CEL (4)
13V-11Cr-3Al	0.027	0.17	0.027	0.008	–	3.1	13.4	11.4	–	R	CEL (4)
13V-11Cr-3Al	0.021	0.14	0.027	0.010	0.12	3.0	13.6	10.9	–	R	CEL (4)

[a]R = remainder.

[b]Numbers refer to references at end of report.

[c]Nominal compositions.

Table 82. Corrosion Rates and Types of Corrosion of Titanium Alloys

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Corrosion Type[b]	Source[c]
Titanium	W	123	5,640	<0.1	NC	INCO (3)
Titanium	W	123	5,640	0.19	NC	MEL (5)
Titanium	S	123	5,640	<0.1	NC	INCO (3)
Titanium	W	403	6,780	<0.1	NC	INCO (3)
Titanium	S	403	6,780	<0.1	NC	INCO (3)
Titanium	W	751	5,640	<0.1	NC	INCO (3)
Titanium	W	751	5,640	<0.1	NC	MEL (5)
Titanium	S	751	5,640	<0.1	NC	INCO (3)
Titanium	W	1,064	5,300	<0.1	NC	INCO (3)
Titanium	S	1,064	5,300	<0.1	NC	INCO (3)
Titanium	W	197	2,340	<0.1	NC	INCO (3)
Titanium	W	197	2,340	<0.1	NC	Boeing (6)
Titanium	S	197	2,340	<0.1	NC	INCO (3)
Titanium	W	402	2,370	<0.1	NC	INCO (3)
Titanium	S	402	2,370	<0.1	NC	INCO (3)
Titanium	W	181	5	<0.1	NC	INCO (3)
Titanium	W	366	5	<0.1	NC	INCO (3)
75A	W	123	5,640	0.0	NC	CEL (4)
75A	S	123	5,640	0.0	NC	CEL (4)
75A[d]	W	189	5,900	0.0	NC	CEL (4)
75A[e]	W	189	5,900	0.0	NC	CEL (4)
75A[d]	S	189	5,900	0.0	NC; BD	CEL (4)
75A[e]	S	189	5,900	0.0	NC; BD	CEL (4)
75A	W	403	6,780	0.0	NC	CEL (4)
75A	S	403	6,780	0.0	NC	CEL (4)
75A	W	751	5,640	0.0	NC	CEL (4)
75A	W	197	2,340	0.0	NC	CEL (4)
75A	S	197	2,340	0.0	NC	CEL (4)
75A	W	402	2,370	0.0	NC	CEL (4)
75A	S	402	2,370	0.0	NC	CEL (4)
75A	W	181	5	0.0	NC; FS	CEL (4)
75A[d]	W	181	5	0.0	NC; FS	CEL (4)
75A[e]	W	181	5	0.0	NC; FS	CEL (4)
75A	W	398	5	0.0	NC	CEL (4)
75A[d]	W	398	5	0.0	NC	CEL (4)
75A[e]	W	398	5	0.0	NC	CEL (4)
75A	W	540	5	0.0	NC	CEL (4)
75A[d]	W	540	5	0.0	NC	CEL (4)
75A[e]	W	540	5	0.0	NC	CEL (4)

Continued

Table 82. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Corrosion Type[b]	Source[c]
75A	W	588	5	0.0	NC	CEL (4)
75A[d]	W	588	5	0.0	NC	CEL (4)
75A[e]	W	588	5	0.0	NC	CEL (4)
0.15 Pd[d]	W	189	5,900	0.0	NC	CEL (4)
0.15 Pd[e]	W	189	5,900	0.0	NC	CEL (4)
0.15 Pd[d]	S	189	5,900	0.0	NC; BD	CEL (4)
0.15 Pd[e]	S	189	5,900	0.0	NC; BD	CEL (4)
0.15 Pd[d]	W	181	5	0.0	NC; FS	CEL (4)
0.15 Pd[e]	W	181	5	0.0	NC; FS	CEL (4)
0.15 Pd[d]	W	398	5	0.0	NC	CEL (4)
0.15 Pd[e]	W	398	5	0.0	NC	CEL (4)
0.15 Pd[d]	W	540	5	0.0	NC	CEL (4)
0.15 Pd[e]	W	540	5	0.0	NC	CEL (4)
0.15 Pd[d]	W	588	5	0.0	NC	CEL (4)
0.15 Pd[e]	W	588	5	0.0	NC	CEL (4)
5Al-2.5Sn[d]	W	123	5,640	<0.1	NC	CEL (4)
5Al-2.5Sn[e]	W	123	5,640	0.0	NC	CEL (4)
5Al-2.5Sn[d]	S	123	5,640	<0.1	NC	CEL (4)
5Al-2.5Sn[e]	S	123	5,640	0.0	NC	CEL (4)
5Al-2.5Sn[d]	W	189	5,900	0.0	NC	CEL (4)
5Al-2.5Sn[e]	W	189	5,900	0.0	NC	CEL (4)
5Al-2.5Sn[d]	S	189	5,900	0.0	NC; BD	CEL (4)
5Al-2.5Sn[e]	S	189	5,900	0.0	NC; BD	CEL (4)
5Al-2.5Sn[d]	W	403	6,780	0.0	NC	CEL (4)
5Al-2.5Sn[e]	W	403	6,780	0.0	NC	CEL (4)
5Al-2.5Sn[d]	S	403	6,780	0.0	NC	CEL (4)
5Al-2.5Sn[e]	S	403	6,780	0.0	NC	CEL (4)
5Al-2.5Sn[d]	W	751	5,640	0.0	NC	CEL (4)
5Al-2.5Sn[e]	W	751	5,640	0.0	NC	CEL (4)
5Al-2.5Sn[d]	W	197	2,340	0.0	NC	CEL (4)
5Al-2.5Sn[e]	W	197	2,340	0.0	NC	CEL (4)
5Al-2.5Sn[d]	S	197	2,340	0.0	NC	CEL (4)
5Al-2.5Sn[e]	S	197	2,340	0.0	NC	CEL (4)
5Al-2.5Sn[d]	W	402	2,370	0.0	NC	CEL (4)
5Al-2.5Sn[e]	W	402	2,370	0.0	NC	CEL (4)
5Al-2.5Sn[d]	S	402	2,370	0.0	NC	CEL (4)
5Al-2.5Sn[e]	S	402	2,370	0.0	NC	CEL (4)
5Al-2.5Sn[d]	W	181	5	0.0	NC; FS	CEL (4)
5Al-2.5Sn[e]	W	181	5	0.0	NC; FS	CEL (4)

Continued

Table 82. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Corrosion Type[b]	Source[c]
5Al-2.5Sn[d]	W	398	5	0.0	NC	CEL (4)
5Al-2.5Sn[e]	W	398	5	0.0	NC	CEL (4)
5Al-2.5Sn[d]	W	540	5	0.0	NC	CEL (4)
5Al-2.5Sn[e]	W	540	5	0.0	NC	CEL (4)
5Al-2.5Sn[d]	W	588	5	0.0	NC	CEL (4)
7Al-2Cb-1Ta[d]	W	189	5,900	0.0	NC	CEL (4)
7Al-2Cb-1Ta[e]	W	189	5,900	0.0	NC	CEL (4)
7Al-2Cb-1Ta[d]	S	189	5,900	0.0	NC; BD	CEL (4)
7Al-2Cb-1Ta[e]	S	189	5,900	0.0	NC; BD	CEL (4)
7Al-2Cb-1Ta[d]	W	181	5	0.0	NC; FS	CEL (4)
7Al-2Cb-1Ta[e]	W	181	5	0.0	NC; FS	CEL (4)
7Al-2Cb-1Ta[d]	W	398	5	0.0	NC	CEL (4)
7Al-2Cb-1Ta[e]	W	398	5	0.0	NC	CEL (4)
7Al-2Cb-1Ta[d]	W	540	5	0.0	NC	CEL (4)
7Al-2Cb-1Ta[e]	W	540	5	0.0	NC	CEL (4)
7Al-2Cb-1Ta[d]	W	588	5	0.0	NC	CEL (4)
7Al-2Cb-1Ta[e]	W	588	5	0.0	NC	CEL (4)
4Al-3Mo-1V	W	123	5,640	0.0	NC	NADC (7)
4Al-3Mo-1V	W	403	6,780	0.0	NC	NADC (7)
4Al-3Mo-1V	S	403	6,780	0.0	NC; BD	NADC (7)
4Al-3Mo-1V	W	751	5,640	0.0	NC	NADC (7)
4Al-3Mo-1V	S	751	5,640	0.0	NC; BD	NADC (7)
4Al-3Mo-1V	W	1,064	5,300	0.0	NC	CEL (4)
4Al-3Mo-1V	W	1,064	5,300	0.0	NC	NADC (7)
4Al-3Mo-1V	S	1,064	5,300	0.0	NC; BD	NADC (7)
4Al-3Mo-1V	W	197	2,340	0.0	NC	NADC (7)
4Al-3Mo-1V	S	197	2,340	0.0	NC; BD	NADC (7)
4Al-3Mo-1V	W	402	2,370	0.0	NC	CEL (4)
4Al-3Mo-1V	S	402	2,370	0.0	NC	CEL (4)
8 Mn	W	402	2,370	0.0	NC	CEL (4)
8 Mn	S	402	2,370	0.0	NC	CEL (4)
140A	W	1,064	5,300	0.0	NC	CEL (4)
7Al-12Zr	W	123	5,300	<0.1	NC	NADC (7)
6Al-4V	W	123	5,640	<0.1	NC	NADC (7)
6Al-4V	W	123	5,640	0.18	NC	MEL (5)
6Al-4V	W	123	5,640	0.0	NC	CEL (4)
6Al-4V[d]	W	123	5,640	0.0	NC	CEL (4)

Continued

Table 82. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion		Source[c]
				Rate (mpy)	Type[b]	
6Al-4V[e]	W	123	5,640	0.0	NC	CEL (4)
6Al-4V	S	123	5,640	0.0	NC	CEL (4)
6Al-4V[d]	S	123	5,640	0.0	NC	CEL (4)
6Al-4V[e]	S	123	5,640	0.0	NC	CEL (4)
6Al-4V[d]	W	189	5,900	0.0	NC	CEL (4)
6Al-4V[e]	W	189	5,900	0.0	NC	CEL (4)
6Al-4V[d]	S	189	5,900	0.0	NC; BD	CEL (4)
6Al-4V[e]	S	189	5,900	0.0	NC; BD	CEL (4)
6Al-4V	W	403	6,780	0.0	NC	NADC (7)
6Al-4V[f]	W	403	6,780	0.0	NC	NADC (7)
6Al-4V	W	403	6,780	0.0	NC	CEL (4)
6Al-4V[d]	W	403	6,780	0.0	NC	CEL (4)
6Al-4V[e]	W	403	6,780	0.0	NC	CEL (4)
6Al-4V	S	403	6,780	0.0	NC	CEL (4)
6Al-4V[d]	S	403	6,780	0.0	NC	CEL (4)
6Al-4V[e]	S	403	6,780	0.0	NC	CEL (4)
6Al-4V	W	751	5,640	0.0	NC	NADC (7)
6Al-4V	W	751	5,640	<0.1	NC	MEL (5)
6Al-4V	W	751	5,640	0.0	NC	CEL (4)
6Al-4V[d]	W	751	5,640	0.0	NC	CEL (4)
6Al-4V[e]	W	751	5,640	0.0	NC	CEL (4)
6Al-4V	W	1,064	5,300	0.0	NC	CEL (4)
6Al-4V	W	197	2,340	0.0	NC	NADC (7)
6Al-4V[f]	W	197	2,340	0.0	HAZ (CR)[g]	NADC (7)
6Al-4V	W	197	2,340	0.0	NC	CEL (4)
6Al-4V[d]	W	197	2,340	0.0	NC	CEL (4)
6Al-4V[e]	W	197	2,340	0.0	NC	CEL (4)
6Al-4V	S	197	2,340	0.0	NC; BD	NADC (7)
6Al-4V	S	197	2,340	0.0	NC	CEL (4)
6Al-4V[d]	S	197	2,340	0.0	NC	CEL (4)
6Al-4V[e]	S	197	2,340	0.0	NC	CEL (4)
6Al-4V	W	402	2,370	0.0	NC	NADC (7)
6Al-4V	W	402	2,370	0.0	NC	CEL (4)
6Al-4V[d]	W	402	2,370	0.0	NC	CEL (4)
6Al-4V[e]	W	402	2,370	0.0	NC	CEL (4)
6Al-4V	S	402	2,370	0.0	NC	CEL (4)
6Al-4V[d]	S	402	2,370	0.0	NC	CEL (4)
6Al-4V[e]	S	402	2,370	0.0	NC	CEL (4)
6Al-4V	W	181	5	0.0	NC; FS	CEL (4)
6Al-4V[d]	W	181	5	0.0	NC; FS	CEL (4)

Continued

Table 82. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Corrosion Type[b]	Source[c]
6Al-4V[e]	W	181	5	0.0	NC; FS	CEL (4)
6Al-4V	W	398	5	0.0	NC	CEL (4)
6Al-4V[d]	W	398	5	0.0	NC	CEL (4)
6Al-4V[e]	W	398	5	0.0	NC	CEL (4)
6Al-4V	W	540	5	0.0	NC	CEL (4)
6Al-4V[d]	W	540	5	0.0	NC	CEL (4)
6Al-4V[e]	W	540	5	0.0	NC	CEL (4)
6Al-4V[d]	W	588	5	0.0	NC	CEL (4)
6Al-4V[e]	W	588	5	0.0	NC	CEL (4)
6Al-2Cb-1Ta-1Mo	W	189	5,900	0.0	NC	CEL (4)
6Al-2Cb-1Ta-1Mo[d]	W	189	5,900	0.0	NC	CEL (4)
6Al-2Cb-1Ta-1Mo[e]	W	189	5,900	0.0	NC	CEL (4)
6Al-2Cb-1Ta-1Mo	S	189	5,900	0.0	NC; BD	CEL (4)
6Al-2Cb-1Ta-1Mo[d]	S	189	5,900	0.0	NC; BD	CEL (4)
6Al-2Cb-1Ta-1Mo[e]	S	189	5,900	0.0	NC; BD	CEL (4)
13V-11Cr-3Al	W	123	5,640	<0.1	NC	MEL (5)
13V-11Cr-3Al[d]	W	123	5,640	0.0	NC	CEL (4)
13V-11Cr-3Al[e]	W	123	5,640	0.0	NC	CEL (4)
13V-11Cr-3Al[d]	S	123	5,640	0.0	NC	CEL (4)
13V-11Cr-3Al[e]	S	123	5,640	0.0	NC	CEL (4)
13V-11Cr-3Al[d]	W	189	5,900	0.0	NC	CEL (4)
13V-11Cr-3Al[e]	W	189	5,900	0.0	NC	CEL (4)
13V-11Cr-3Al[d]	S	189	5,900	0.0	SCC[h]	CEL (4)
13V-11Cr-3Al[e]	S	189	5,900	0.0	NC; BD	CEL (4)
13V-11Cr-3Al[d,i]	W	360	4,200	0.0	SCC[j]	CEL (4)
13V-11Cr-3Al[d,i]	S	360	4,200	0.0	NC	CEL (4)
13V-11Cr-3Al[d]	W	403	6,780	0.0	NC	CEL (4)
13V-11Cr-3Al[e]	W	403	6,780	0.0	NC	CEL (4)
13V-11Cr-3Al[d]	S	403	6,780	0.0	SCC[j]	CEL (4)
13V-11Cr-3Al[e]	S	403	6,780	0.0	NC	CEL (4)
13V-11Cr-3Al	W	751	5,640	<0.1	NC	MEL (5)
13V-11Cr-3Al[d]	W	751	5,640	0.0	SCC[j]	CEL (4)
13V-11Cr-3Al[e]	W	751	5,640	0.0	NC	CEL (4)
13V-11Cr-3Al[d]	W	197	2,340	0.0	NC	CEL (4)
13V-11Cr-3Al[e]	W	197	2,340	0.0	NC	CEL (4)
13V-11Cr-3Al[d]	S	197	2,340	0.0	NC	CEL (4)
13V-11Cr-3Al[e]	S	197	2,340	0.0	NC	CEL (4)
13V-11Cr-3Al[d]	W	402	2,370	0.0	NC	CEL (4)
13V-11Cr-3Al[e]	W	402	2,370	0.0	NC	CEL (4)
13V-11Cr-3Al[d]	S	402	2,370	0.0	SCC[j]	CEL (4)

Continued

Table 82. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion		Source[c]
				Rate (mpy)	Type[b]	
13V-11Cr-3Al[e]	S	402	2,370	0.0	NC	CEL (4)
13V-11Cr-3Al[d]	W	181	5	0.0	SCC[j]	CEL (4)
13V-11Cr-3Al[e]	W	181	5	0.0	NC; FS	CEL (4)
13V-11Cr-3Al[d]	W	398	5	0.0	SCC (6)[j]	CEL (4)
13V-11Cr-3Al[e]	W	398	5	0.0	SCC (2)[k]	CEL (4)
13V-11Cr-3Al[d]	W	540	5	0.0	SCC (12)[j]	CEL (4)
13V-11Cr-3Al[e]	W	540	5	0.0	SCC (1)[k]	CEL (4)
13V-11Cr-3Al[d]	W	588	5	0.0	SCC (19)[j]	CEL (4)
13V-11Cr-3Al[e]	W	588	5	0.0	SCC (1)[k]	CEL (4)

[a] W = Totally exposed in seawater on sides of structure; S = Exposed in base of structure so that the lower portions of the specimens were embedded in the bottom sediments.

[b] Symbols for types of corrosion:

BD = Bluish discoloration on portion in bottom sediment.
CR = Cracked
FS = Fouling stains
HAZ = Heat-affected zone
NC = No visible corrosion
SCC = Stress corrosion cracking

Numbers in parentheses are number of stress corrosion cracks

[c] Numbers refer to references at end of report.

[d] Unrelieved 3-in.-diam weld bead in center of specimen, TIG process, nonconsumable tungsten electrode.

[e] Unrelieved butt weld across width of specimen, TIG process, nonconsumable tungsten electrode.

[f] TIG welded, commercially pure titanium filler metal used, unrelieved.

[g] Cracked in heat-affected zone of unrelieved transverse butt weld.

[h] Two cracks in each specimen perpendicular to and across circular weld beads; some branching; penetrated through 0.125-in.-thick plate. Bluish discoloration on portions of specimens in sediment.

[i] Exposed in Tongue-of-the-Ocean, Atlantic, 0.3-kt current, 4.5°C, 5.18-ml/l oxygen.

[j] Cracks radially across circular weld bead into base metal outside heat-affected zone.

[k] Cracks across weld bead normal to direction of welding.

Table 83. Stress Corrosion of Titanium Alloys

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed	Source[a]
75A[b]	41	50	189	5,900	3	0	CEL (4)
75A[b,c]	41	50	189	5,900	3	0	CEL (4)
75A[b]	62	75	189	5,900	3	0	CEL (4)
75A[b,c]	62	75	189	5,900	3	0	CEL (4)
75A	25	35	403	6,780	2	0	CEL (4)
75A	35	50	403	6,780	2	0	CEL (4)
75A	53	75	403	6,780	2	0	CEL (4)
75A	25	35	197	2,340	3	0	CEL (4)
75A	35	50	197	2,340	3	0	CEL (4)
75A	53	75	197	2,340	3	0	CEL (4)
75A	35	50	402	2,370	3	0	CEL (4)
75A	53	75	402	2,370	3	0	CEL (4)
75A[b]	29	35	180	5	3	0	CEL (4)
75A[b]	41	50	180	5	3	0	CEL (4)
75A[b]	62	75	180	5	3	0	CEL (4)
75A[d]	*e*	—	181	5	4	0	CEL (4)
0.15 Pd[b]	25	50	189	5,900	3	0	CEL (4)
0.15 Pd[b,c]	25	50	189	5,900	3	0	CEL (4)
0.15 Pd[b]	37	75	189	5,900	3	0	CEL (4)
0.15 Pd[b,c]	37	75	189	5,900	3	0	CEL (4)
0.15 Pd[b]	24	35	180	5	3	0	CEL (4)
0.15 Pd[b]	34	50	180	5	3	0	CEL (4)
0.15 Pd[b]	51	75	180	5	3	0	CEL (4)
0.15 Pd[d]	*e*	—	181	5	4	0	CEL (4)
5Al-2.5Sn[b]	43	35	123	5,640	3	0	CEL (4)
5Al-2.5Sn[b]	61	50	123	5,640	3	0	CEL (4)
5Al-2.5Sn[b]	92	75	123	5,640	3	0	CEL (4)
5Al-2.5Sn[d]	*e*	—	123	5,640	3	0	CEL (4)
5Al-2.5Sn[b]	62	50	189	5,900	3	0	CEL (4)
5Al-2.5Sn[b,c]	62	50	189	5,900	3	0	CEL (4)
5Al-2.5Sn[b]	93	75	189	5,900	3	0	CEL (4)
5Al-2.5Sn[b,c]	93	75	189	5,900	3	0	CEL (4)
5Al-2.5Sn[b]	43	35	403	6,780	2	0	CEL (4)
5Al-2.5Sn[b]	61	50	403	6,780	2	0	CEL (4)
5Al-2.5Sn[b]	92	75	403	6,780	2	0	CEL (4)
5Al-2.5Sn[d]	*e*	—	403	6,780	2	0	CEL (4)
5Al-2.5Sn[b]	43	35	751	5,640	3	0	CEL (4)
5Al-2.5Sn[b]	61	50	751	5,640	3	0	CEL (4)
5Al-2.5Sn[b]	92	75	751	5,640	3	0	CEL (4)
5Al-2.5Sn[d]	*e*	—	751	5,640	3	0	CEL (4)

Continued

Table 83. Continued.

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed	Source[a]
5Al-2.5Sn[b]	43	35	197	2,340	3	0	CEL (4)
5Al-2.5Sn[b]	61	50	197	2,340	3	0	CEL (4)
5Al-2.5Sn[b]	92	75	197	2,340	3	0	CEL (4)
5Al-2.5Sn[d]	*e*	–	197	2,340	2	0	CEL (4)
5Al-2.5Sn[b]	*e*	–	402	2,370	2	0	CEL (4)
5Al-2.5Sn[b]	43	35	180	5	3	0	CEL (4)
5Al-2.5Sn[b]	62	50	180	5	3	0	CEL (4)
5Al-2.5Sn[b]	93	75	180	5	3	0	CEL (4)
5Al-2.5Sn[d]	*e*	–	181	5	4	0	CEL (4)
7Al-2Cb-1Ta[b]	50	50	189	5,900	3	0	CEL (4)
7Al-2Cb-1Ta[b,c]	50	50	189	5,900	3	0	CEL (4)
7Al-2Cb-1Ta[b]	75	75	189	5,900	3	0	CEL (4)
7Al-2Cb-1Ta[b,c]	75	75	189	5,900	3	0	CEL (4)
7Al-2Cb-1Ta[b]	35	35	180	5	3	0	CEL (4)
7Al-2Cb-1Ta[b]	50	50	180	5	3	0	CEL (4)
7Al-2Cb-1Ta[b]	75	75	180	5	3	0	CEL (4)
7Al-2Cb-1Ta[d]	*e*	–	181	5	4	0	CEL (4)
6Al-2Cb-1Ta-1Mo[b]	60	50	189	5,900	3	0	CEL (4)
6Al-2Cb-1Ta-1Mo[b,c]	60	50	189	5,900	3	0	CEL (4)
6Al-2Cb-1Ta-1Mo[b]	89	75	189	5,900	3	0	CEL (4)
6Al-2Cb-1Ta-1Mo[b,c]	89	75	189	5,900	3	0	CEL (4)
6Al-4V	48	35	123	5,640	3	0	CEL (4)
6Al-4V[b]	49	35	123	5,640	3	0	CEL (4)
6Al-4V	68	50	123	5,640	3	0	CEL (4)
6Al-4V[b]	70	50	123	5,640	3	0	CEL (4)
6Al-4V	102	75	123	5,640	3	0	CEL (4)
6Al-4V[b]	105	75	123	5,640	3	0	CEL (4)
6Al-4V[d]	*e*	–	123	5,640	2	0	CEL (4)
6Al-4V[b]	66	50	189	5,900	3	0	CEL (4)
6Al-4V[b,c]	66	50	189	5,900	3	0	CEL (4)
6Al-4V[b]	99	75	189	5,900	3	0	CEL (4)
6Al-4V[b,c]	99	75	189	5,900	3	0	CEL (4)
6Al-4V	43	30	403	6,780	3	0	NADC (7)
6Al-4V	48	35	403	6,780	2	0	CEL (4)
6Al-4V[b]	49	35	403	6,780	2	0	CEL (4)
6Al-4V	71	50	403	6,780	3	0	NADC (7)
6Al-4V	68	50	403	6,780	2	0	CEL (4)
6Al-4V[b]	70	50	403	6,780	2	0	CEL (4)
6Al-4V	107	75	403	6,780	3	0	NADC (7)
6Al-4V	102	75	403	6,780	2	0	CEL (4)

Continued

Table 83. Continued.

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed	Source[a]
6Al-4V[b]	105	75	403	6,780	2	0	CEL (4)
6Al-4V[d]	*e*	—	403	6,780	2	0	CEL (4)
6Al-4V	48	35	751	5,640	3	0	CEL (4)
6Al-4V[b]	49	35	751	5,640	3	0	CEL (4)
6Al-4V	68	50	751	5,640	3	0	CEL (4)
6Al-4V[b]	70	50	751	5,640	3	0	CEL (4)
6Al-4V	102	75	751	5,640	3	0	CEL (4)
6Al-4V[b]	105	75	751	5,640	3	0	CEL (4)
6Al-4V[d]	*e*	—	751	5,640	2	0	CEL (4)
6Al-4V	43	30	197	2,340	3	0	NADC (7)
6Al-4V	48	35	197	2,340	3	0	CEL (4)
6Al-4V[b]	49	35	197	2,340	3	0	CEL (4)
6Al-4V	68	50	197	2,340	3	0	CEL (4)
6Al-4V[b]	70	50	197	2,340	3	0	CEL (4)
6Al-4V	107	75	197	2,340	3	0	NADC (7)
6Al-4V	102	75	197	2,340	3	0	CEL (4)
6Al-4V[b]	105	75	197	2,340	3	0	CEL (4)
6Al-4V[d]	*e*	—	197	2,340	2	0	CEL (4)
6Al-4V	43	30	402	2,370	3	0	NADC (7)
6Al-4V	68	50	402	2,370	3	0	CEL (4)
6Al-4V	107	75	402	2,370	3	0	NADC (7)
6Al-4V	102	75	402	2,370	3	0	CEL (4)
6Al-4V[d]	*e*	—	402	2,370	2	0	CEL (4)
6Al-4V[b]	46	35	180	5	3	0	CEL (4)
6Al-4V[b]	66	50	180	5	3	0	CEL (4)
6Al-4V[b]	99	75	180	5	3	0	CEL (4)
6Al-4V[d]	*e*	—	181	5	4	0	CEL (4)
13V-11Cr-3Al[b]	49	35	123	5,640	3	0	CEL (4)
13V-11Cr-3Al[b]	70	50	123	5,640	3	0	CEL (4)
13V-11Cr-3Al[b]	105	75	123	5,640	3	0	CEL (4)
13V-11Cr-3Al[d]	*e*	—	123	5,640	2	0	CEL (4)
13V-11Cr-3Al[b]	63	50	189	5,900	3	0	CEL (4)
13V-11Cr-3Al[b,c]	63	50	189	5,900	3	0	CEL (4)
13V-11Cr-3Al[b]	95	75	189	5,900	3	0	CEL (4)
13V-11Cr-3Al[b,c]	95	75	189	5,900	3	0	CEL (4)
13V-11Cr-3Al[d]	*e*	—	189	5,900	2	1[f]	CEL (4)
13V-11Cr-3Al[b]	49	35	403	6,780	2	0	CEL (4)
13V-11Cr-3Al[b]	70	50	403	6,780	2	0	CEL (4)
13V-11Cr-3Al[b]	105	75	403	6,780	2	0	CEL (4)
13V-11Cr-3Al[d]	*e*	—	403	6,780	2	1[f]	CEL (4)
13V-11Cr-3Al[b]	49	35	751	5,640	3	0	CEL (4)

Continued

Table 83. Continued.

Alloy	Stress (ksi)	Percent Yield Strength	Exposure (day)	Depth (ft)	Number of Specimens Exposed	Number Failed	Source[a]
13V-11Cr-3Al[b]	70	50	751	5,640	3	0	CEL (4)
13V-11Cr-3Al[b]	105	75	751	5,640	3	0	CEL (4)
13V-11Cr-3Al[d]	*e*	—	751	5,640	2	1[g]	CEL (4)
13V-11Cr-3Al[b]	49	35	197	2,340	3	0	CEL (4)
13V-11Cr-3Al[b]	70	50	197	2,340	3	0	CEL (4)
13V-11Cr-3Al[b]	105	75	197	2,340	3	0	CEL (4)
13V-11Cr-3Al[d]	*e*	—	197	2,340	3	0	CEL (4)
13V-11Cr-3Al[d]	*e*	—	402	2,370	2	1[f]	CEL (4)
13V-11Cr-3Al[b]	44	35	180	5	3	0	CEL (4)
13V-11Cr-3Al[b]	63	50	180	5	3	0	CEL (4)
13V-11Cr-3Al[b]	95	75	180	5	3	3[h]	CEL (4)
13V-11Cr-3Al[d]	*e*	—	181	5	4	1[g]	CEL (4)
13V-11Cr-3Al[b]	*e*	—	398	5	2	2[i]	CEL (4)
13V-11Cr-3Al[d]	*e*	—	398	5	2	2[j]	CEL (4)
13V-11Cr-3Al[b]	*e*	—	540	5	2	1[i]	CEL (4)
13V-11Cr-3Al[d]	*e*	—	540	5	2	2[k]	CEL (4)
13V-11Cr-3Al[b]	*e*	—	588	5	2	1[i]	CEL (4)
13V-11Cr-3Al[d]	*e*	—	588	5	2	2[l]	CEL (4)

[a] Numbers refer to references at end of report.

[b] Unrelieved butt weld across width of specimen, TIG process, nonconsumable tungsten electrode, weld at apex of bow.

[c] Partially embedded in bottom sediment.

[d] Unrelieved 3-in.-diam weld bead in center of specimen, TIG process, nonconsumable tungsten electrode.

[e] Residual welding stresses.

[f] Specimen partially embedded in bottom sediment; cracked radially across the weld bead.

[g] Specimen in seawater; cracked radially across the weld bead.

[h] Specimens failed in heat-affected zones after 35, 77, and 105 days of exposure.

[i] Cracks across weld beads.

[j] Six cracks radially across weld beads.

[k] Twelve cracks radially across weld beads.

[l] Nineteen cracks radially across weld beads.

Table 84. Changes in Mechanical Properties of Titanium Alloys Due to Corrosion

Alloy	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[a]
			Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
75A	123	5,640	87	+4	70	+5	30	-5	CEL (4)
75A	403	6,780	87	+4	70	+4	30	-16	CEL (4)
75A	751	5,640	87	+4	70	+11	30	-15	CEL (4)
75A	197	2,340	87	+5	70	+8	30	-11	CEL (4)
75A	402	2,370	87	+6	70	+7	30	-13	CEL (4)
75A	181	5	87	+8	70	+9	30	-18	CEL (4)
75A[b]	181	5	101	+2	84	-1	25	-24	CEL (4)
0.15 Pd[b]	181	5	66	+3	47	+4	28	-33	CEL (4)
5Al-2.5Sn[b]	403	6,780	130	+10	123	+10	14	-13	CEL (4)
5Al-2.5Sn[b]	751	5,640	130	+4	123	+5	14	-11	CEL (4)
5Al-2.5Sn[b]	402	2,370	130	+5	123	+4	14	-15	CEL (4)
5Al-2.5Sn[b]	181	5	138	+4	124	+1	17	-20	CEL (4)
8 Mn	402	2,370	132	+2	116	+3	12	+33	CEL (4)
4Al-3Mo-1V	123	5,640	155	0	115	-3	15	0	NADC (7)
4Al-3Mo-1V	403	6,780	155	+2	115	+2	15	0	NADC (7)
4Al-3Mo-1V	751	5,640	155	-17	115	-29	15	0	NADC (7)
4Al-3Mo-1V	1,064	5,300	155	-8	115	-13	15	+7	NADC (7)
4Al-3Mo-1V	402	2,370	201	+1	180	-2	4	+19	CEL (4)
7Al-12Zr	123	5,640	132	+1	126	+1	17	-24	NADC (7)
7Al-2Cb-1Ta[b]	181	5	111	+4	98	+1	18	-16	CEL (4)
6Al-4V	123	5,640	172	-3	143	+7	5	0	NADC (7)
6Al-4V	403	6,780	140	+16	136	+16	14	0	CEL (4)
6Al-4V[b]	403	6,780	148	+4	139	-1	13	-13	CEL (4)
6Al-4V	751	5,640	172	0	143	+8	5	+50	NADC (7)
6Al-4V	751	5,640	140	0	136	+4	14	0	CEL (4)
6Al-4V[b]	751	5,640	148	+3	139	+4	13	-13	CEL (4)
6Al-4V	197	2,340	172	-27	143	-22	5	-40	NADC (7)
6Al-4V	197	2,340	140	+2	136	+3	14	+2	CEL (4)
6Al-4V	402	2,370	140	+7	136	+6	14	-1	CEL (4)
6Al-4V[b]	402	2,370	148	+2	139	+1	13	-8	CEL (4)
6Al-4V	181	5	140	+3	136	+2	14	-9	CEL (4)
6Al-4V[b]	181	5	138	+3	132	-6	14	-29	CEL (4)
13V-11Cr-3Al[b]	403	6,780	144	+18	140	+18	9	-2	CEL (4)
13V-11Cr-3Al[b]	751	5,640	144	+18	140	+20	9	+6	CEL (4)
13V-11Cr-3Al[b]	402	2,370	144	+6	140	+5	9	-22	CEL (4)
13V-11Cr-3Al[b]	181	5	134	+5	126	+8	20	-36	CEL (4)

[a] Numbers refer to references at end of report.

[b] Unrelieved butt weld across width of specimens, TIG process, nonconsumable tungsten electrode.

SECTION 8

MISCELLANEOUS ALLOYS

The miscellaneous alloys are those alloys or metals which are "one of a kind" or do not belong to any of the previous classes of alloys discussed. These alloys would not be considered constructional because of their price, mechanical properties, scarcity, and, in some cases, poor corrosion resistance. Many of them could be used advantageously in specialty or unique applications.

The chemical compositions of the miscellaneous alloys are given in Table 85, and their corrosion rates and types of corrosion in Table 86.

Alloys columbium, gold, platinum, 90% platinum-10% copper, 75% platinum- 25% copper, tantalum, and tantalum-tungsten (Ta60) were uncorroded during exposure both at depth and at the surface.

Alloy MP35N neither corroded nor was susceptible to stress corrosion during 189 days of exposure at the 6,000-foot depth. The MP35N bolts and nuts were in a block of 6Al-4V titanium and were torqued to 50 ft-lb. There was also no galvanic corrosion of either member of the couple.

The corrosion of the three magnesium alloys (M1A, AZ31B, and HK31A) and beryllium was so rapid that their use in seawater would be impractical.

Platinum alloys containing 50 and 75% copper were etched and pitted after 402 days of exposure at the 2,500-foot depth. Such alloys are usually used for contacts in electrical applications. These two alloys would not be satisfactory for use in seawater.

Silver was attacked by the uniform thinning type of corrosion in seawater. The thin tarnish-like film is an excellent insulator; hence, silver could not be used as electrical contacts in seawater.

8.1. DURATION OF EXPOSURE

The effects of duration of exposure on some of the miscellaneous alloys are shown in Figures 18, 19, and 20. The corrosion rates of arsenical, chemical, and tellurium lead, lead-tin solder, tin, and zinc decreased with duration of exposure (Figures 18 and 19), except for lead-tin solder and zinc at the 2,500-foot depth. The corrosion rates of these two alloys increased with increasing time of exposure. At the 6,000-foot depth the corrosion rate of tin increased initially, and, thereafter, decreased with increasing time of exposure. The extremely high corrosion rate for tin after 751 days of exposure (Table 86), obviously, is an error and must be disregarded.

Only surface seawater data were available for molybdenum and tungsten, and the effects of duration of exposure are shown in Figure 20. The corrosion rate of molybdenum decreased, becoming asymptotic with increasing time of exposure. The corrosion rate of tungsten increased linearly with time, at least during the first 760 days of exposure.

8.2. EFFECT OF DEPTH

The effects of depth on the corrosion of some of the miscellaneous alloys after 1 year of exposure are shown in Figure 21. The corrosion of lead, lead-tin solder, molybdenum, tungsten, and tin was greater at the surface than at depth in the Pacific Ocean. Only the corrosion of zinc was greater at depth than at the surface.

8.3. EFFECT OF CONCENTRATION OF OXYGEN

The effects of changes in the concentration of oxygen in seawater are shown in Figure 22. The corrosion rates of arsenical, chemical, and tellurium lead, lead-tin solder, molybdenum, tungsten, and tin were higher at the highest concentration of oxygen than at the lowest, but the increases were not necessarily proportional or linear. Only the corrosion of zinc was not uniformly influenced by changes in the concentration of oxygen in seawater between the limits of 0.4 to 5.75 ml/l.

8.4. MECHANICAL PROPERTIES

The effects of exposure on the mechanical properties of columbium, molybdenum, and tantalum are given in Table 87. The mechanical properties of these three alloys were not impaired by exposure in seawater.

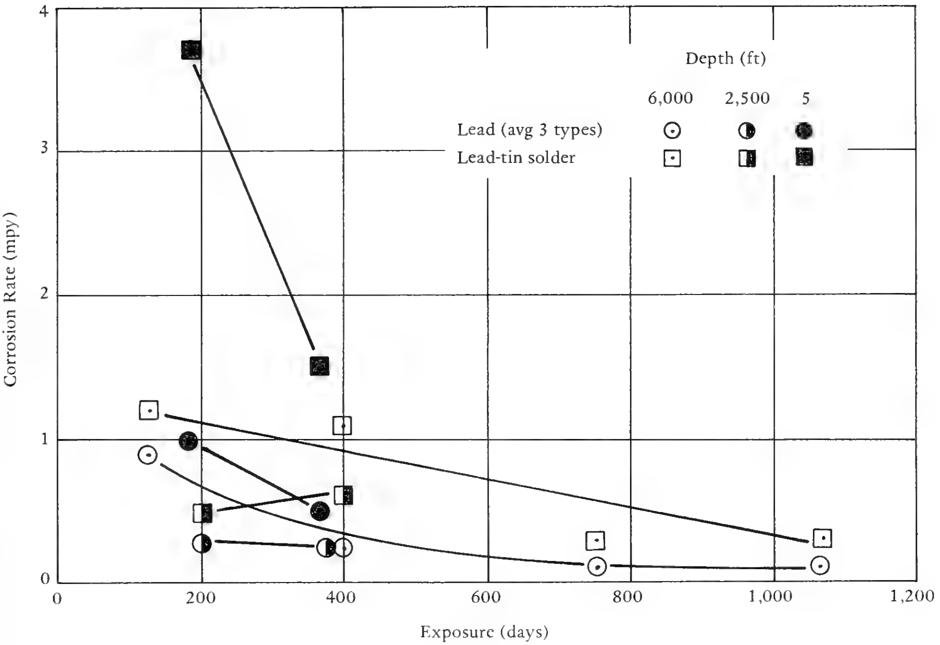

Figure 18. Effect of duration of exposure in seawater on the corrosion of lead and lead-tin solder at the surface and at depth.

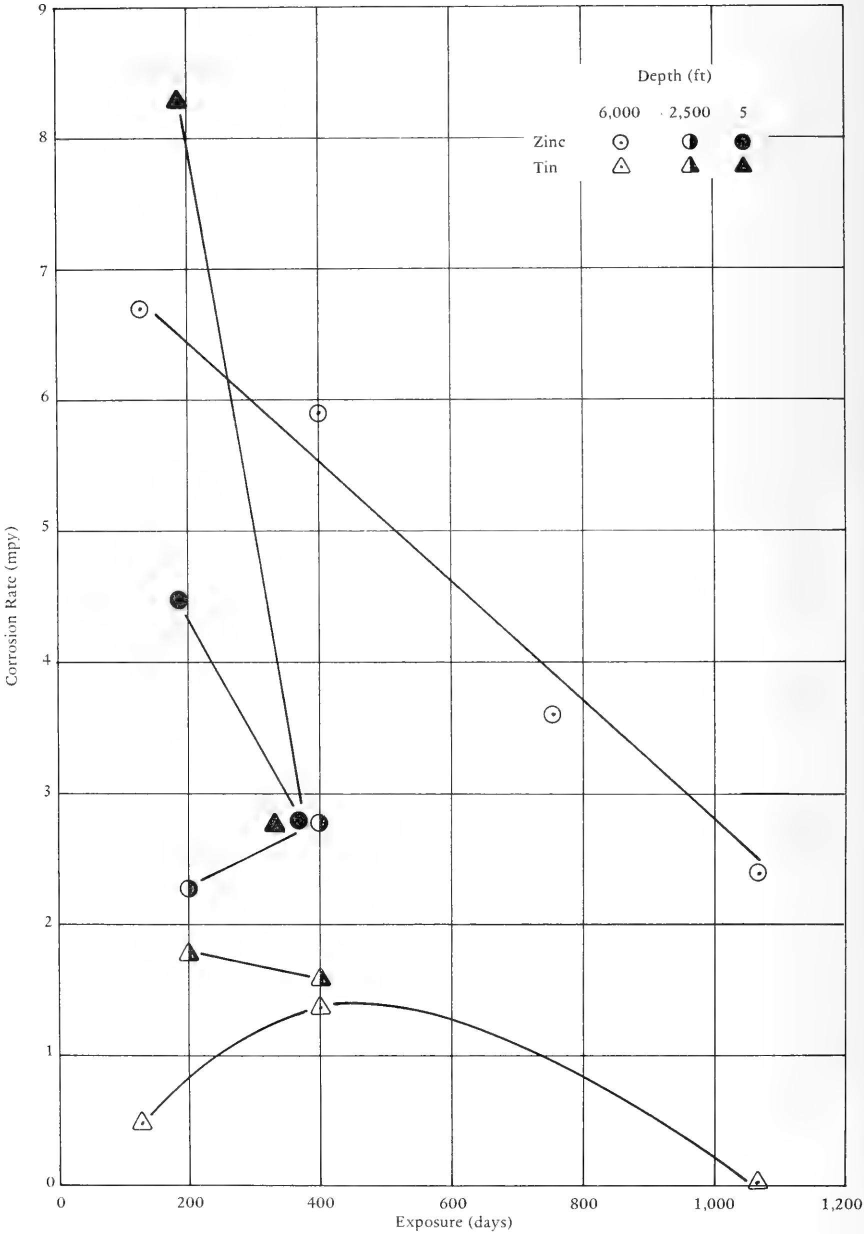

Figure 19. Effect of duration of exposure in seawater on the corrosion of tin and zinc at the surface and at depth.

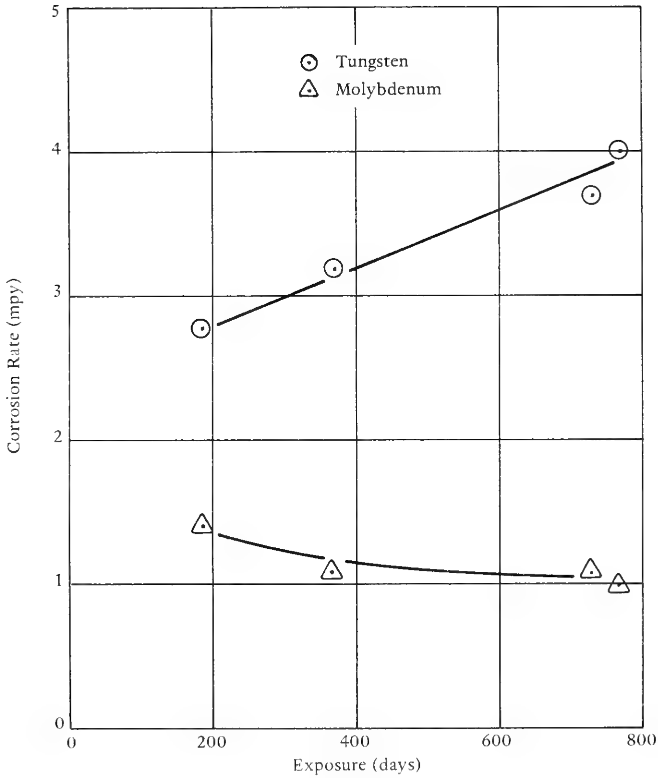

Figure 20. Effect of duration of exposure in surface seawater on the corrosion of molybdenum and tungsten.

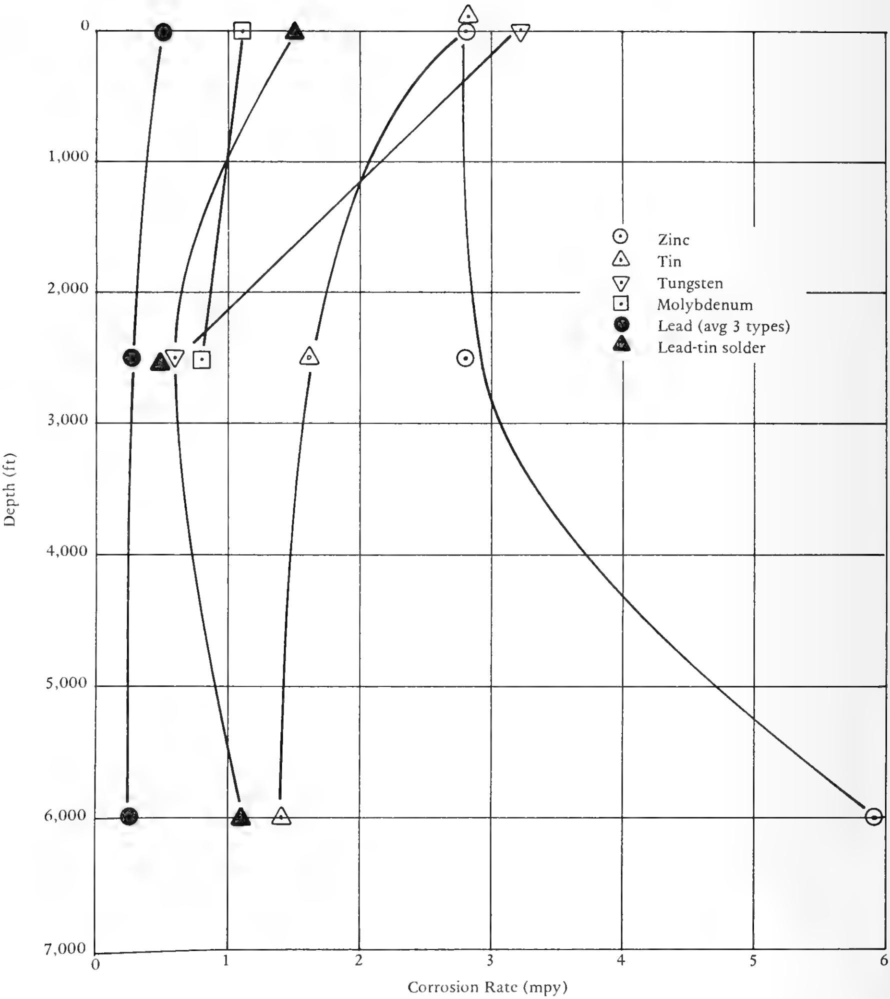

Figure 21. Effect of depth on the corrosion of miscellaneous alloys after 1 year of exposure.

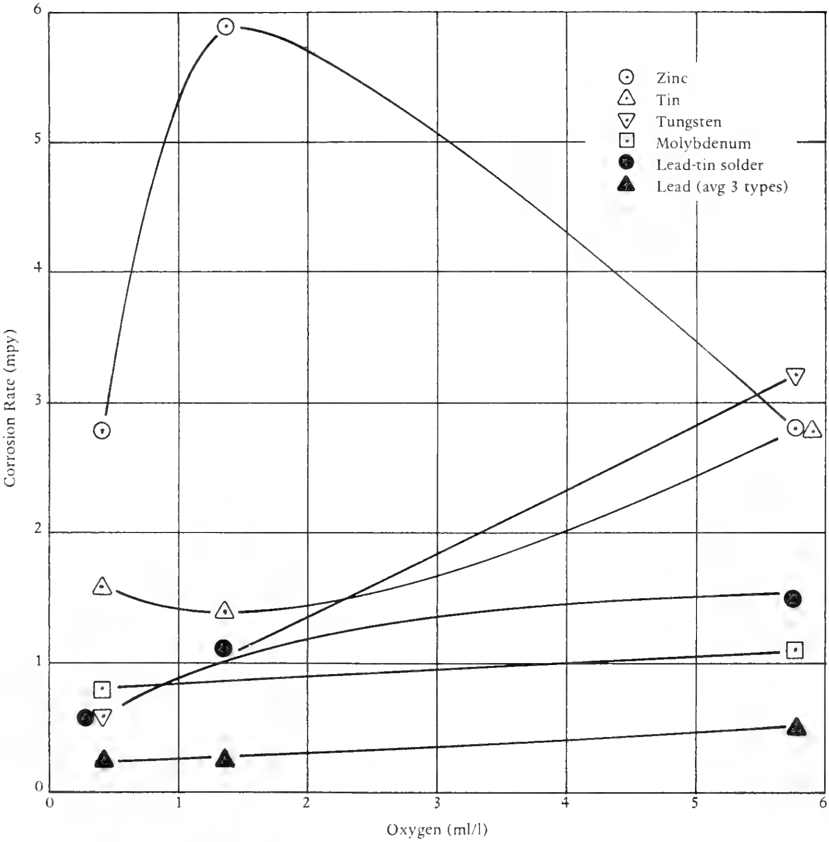

Figure 22. Effect of concentration of oxygen in seawater on the corrosion of miscellaneous alloys after 1 year of exposure.

Table 85. Chemical Composition of Miscellaneous Metals and Alloys, Percent by Weight

Alloy	Chemical Composition	Source[a]
Beryllium	99.0 Be	Boeing (6)
Columbium	99.75 Cb	CEL (4)
Columbium	99.8 Cb	CEL (4)
Gold	99.999 Au	CEL (4)
Lead, antimonial	99 Pb, 6 Sb	INCO (3)
Lead, chemical	99.9 Pb	INCO (3)
Lead, tellurium	99+ Pb, 0.04 Te	INCO (3)
Lead-tin solder	67 Pb, 33 Sn	INCO (3)
Magnesium, MIA	99 Mg, 1 Mn	INCO (3)
Magnesium, AZ31B	96 Mg, 2.6 Al, 1.1 Zn, 0.4 Mn	INCO (3)
Magnesium, AZ31B	95.3 Mg, 3.5 Al, 0.94 Zn, 0.25 Mn	NADC (7)
Magnesium, HK31A	96.2 Mg, 2.67 Th, 0.67 Zr, 0.45 Mn	NADC (7)
Molybdenum	99.9 Mo	CEL (4)
Platinum	99.99 Pt	CEL (4)
Platinum-copper, 90-10	90 Pt, 10 Cu	CEL (4)
Platinum-copper, 75-25	75 Pt, 25 Cu	CEL (4)
Platinum-copper, 50-50	50 Pt, 50 Cu	CEL (4)
Platinum-copper, 25-75	25 Pt, 75 Cu	CEL (4)
Silver	99.999 Ag	CEL (4)
Tantalum	99.9 Ta	CEL (4)
Tantalum	99.9 Ta, 0.010 C, 0.010 O, 0.005 N, 0.002 H	CEL (4)
Tantalum-tungsten, Ta 60	88.8-91.3 Ta, 8.5-11 W	CEL (4)
Tin	99.95 Sn	INCO (3)
Tungsten	99.95 W	CEL (4)
Zinc	99.9 Zn, 0.09 Pb, 0.01 Fe	INCO (3)
MP35N	35 Co, 35 Ni, 20 Cr, 10 Mo	CEL (4)

[a]Numbers refer to references at end of report.

Table 86. Corrosion Rates and Types of Corrosion of Miscellaneous Alloys

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion		Source[c]
				Rate (mpy)	Type[b]	
Beryllium	W	197	2,340	2.0	P (PR)(27)	Boeing (6)
Columbium	W	402	2,370	0.0	NC	CEL (4)
Columbium	S	402	2,370	0.0	NC	CEL (4)
Columbium	W	182	5	0.0	NC	CEL (4)
Columbium	W	364	5	0.0	NC	CEL (4)
Columbium	W	723	5	0.0	NC	CEL (4)
Columbium	W	763	5	0.0	NC	CEL (4)
Gold	W	402	2,370	0.0	NC	CEL (4)
Gold	S	402	2,370	0.0	NC	CEL (4)
Lead, antimonial	W	123	5,640	0.8	U	INCO (3)
Lead, antimonial	S	123	5,640	1.3	U	INCO (3)
Lead, antimonial	W	403	6,780	0.3	U	INCO (3)
Lead, antimonial	S	403	6,780	0.5	U	INCO (3)
Lead, antimonial	W	751	5,640	0.2	U	INCO (3)
Lead, antimonial	S	751	5,640	0.3	U	INCO (3)
Lead, antimonial	W	1,064	5,300	0.2	U	INCO (3)
Lead, antimonial	S	1,064	5,300	0.3	U	INCO (3)
Lead, antimonial	W	197	2,340	0.3	U	INCO (3)
Lead, antimonial	S	197	2,340	0.2	U	INCO (3)
Lead, antimonial	W	402	2,370	0.3	U	INCO (3)
Lead, antimonial	S	402	2,370	0.6	U	INCO (3)
Lead, antimonial	W	182	5	1.2	U	INCO (3)
Lead, antimonial	W	366	5	0.5	U	INCO (3)
Lead, chemical	W	123	5,640	0.8	U	INCO (3)
Lead, chemical	S	123	5,640	0.6	U	INCO (3)
Lead, chemical	W	403	6,780	0.2	U	INCO (3)
Lead, chemical	S	403	6,780	0.1	U	INCO (3)
Lead, chemical	W	751	5,640	0.1	U	INCO (3)
Lead, chemical	S	751	5,640	0.1	U	INCO (3)
Lead, chemical	W	1,064	5,300	0.1	U	INCO (3)
Lead, chemical	S	1,064	5,300	0.3	U	INCO (3)
Lead, chemical	W	197	2,340	0.3	U	INCO (3)
Lead, chemical	S	197	2,340	0.2	U	INCO (3)
Lead, chemical	W	402	2,370	0.2	U	INCO (3)
Lead, chemical	S	402	2,370	0.3	U	INCO (3)
Lead, chemical	W	182	5	0.8	U	INCO (3)
Lead, chemical	W	366	5	0.5	U	INCO (3)
Lead, tellurium	W	123	5,640	1.1	U	INCO (3)
Lead, tellurium	S	123	5,640	1.3	U	INCO (3)
Lead, tellurium	W	403	6,780	0.3	U	INCO (3)
Lead, tellurium	S	403	6,780	0.3	U	INCO (3)
Lead, tellurium	W	751	5,640	0.1	U	INCO (3)
Lead, tellurium	S	751	5,640	0.2	U	INCO (3)
Lead, tellurium	W	1,064	5,300	0.1	U	INCO (3)
Lead, tellurium	S	1,064	5,300	0.3	U	INCO (3)
Lead, tellurium	W	197	2,340	0.3	U	INCO (3)

Continued

Table 86. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion		Source[c]
				Rate (mpy)	Type[b]	
Lead, tellurium	S	197	2,340	0.3	U	INCO (3)
Lead, tellurium	W	402	2,370	0.2	U	INCO (3)
Lead, tellurium	S	402	2,370	0.3	U	INCO (3)
Lead, tellurium	W	182	5	1.0	U	INCO (3)
Lead, tellurium	W	366	5	0.5	U	INCO (3)
Lead-tin solder	W	123	5,640	1.2	U	INCO (3)
Lead-tin solder	S	123	5,640	0.7	U	INCO (3)
Lead-tin solder	W	403	6,780	1.1	U	INCO (3)
Lead-tin solder	S	403	6,780	0.6	U	INCO (3)
Lead-tin solder	W	751	5,640	0.3	U	INCO (3)
Lead-tin solder	S	751	5,640	0.4	U	INCO (3)
Lead-tin solder	W	1,064	5,300	0.3	U	INCO (3)
Lead-tin solder	S	1,064	5,300	0.5	G	INCO (3)
Lead-tin solder	W	197	2,340	0.5	U	INCO (3)
Lead-tin solder	S	197	2,340	0.3	U	INCO (3)
Lead-tin solder	W	402	2,370	0.6	U	INCO (3)
Lead-tin solder	S	402	2,370	0.7	U	INCO (3)
Lead-tin solder	W	182	5	3.7	U	INCO (3)
Lead-tin solder	W	366	5	1.5	G	INCO (3)
Magnesium, M1A	W	123	5,640	42.0	S	INCO (3)
Magnesium, M1A	S	123	5,640	43.0	S	INCO (3)
Magnesium, M1A	W	403	6,780	>20.0	100C	INCO (3)
Magnesium, M1A	S	403	6,780	7.3	S-G	INCO (3)
Magnesium, M1A	W	751	5,640	>10.0	100C	INCO (3)
Magnesium, M1A	S	751	5,640	>12.0	100C	INCO (3)
Magnesium, M1A	W	1,064	5,300	–	100C	INCO (3)
Magnesium, M1A	S	1,064	5,300	2.9	S	INCO (3)
Magnesium, M1A	W	197	2,340	–	100C	INCO (3)
Magnesium, M1A	S	197	2,340	9.0	S	INCO (3)
Magnesium, AZ31B	W	123	5,640	>59.0	100C	INCO (3)
Magnesium, AZ31B	W	123	5,640	–	P (PR)	NADC (7)
Magnesium, AZ31B	S	123	5,640	27.0	S	INCO (3)
Magnesium, AZ31B	W	403	6,780	>20.0	100C	INCO (3)
Magnesium, AZ31B	W	403	6,780	–	N-P (PR)	NADC (7)
Magnesium, AZ31B	S	403	6,780	6.6	S-G	INCO (3)
Magnesium, AZ31B	W	751	5,640	>10.0	100C	INCO (3)
Magnesium, AZ31B	S	751	5,640	>10.0	100C	INCO (3)
Magnesium, AZ31B	W	1,064	5,300	–	100C	INCO (3)
Magnesium, AZ31B	S	1,064	5,300	> 7.0	100C	INCO (3)
Magnesium, AZ31B	W	197	2,340	–	100C	INCO (3)
Magnesium, AZ31B	W	197	2,340	–	EX-G	NADC (7)
Magnesium, AZ31B	S	197	2,340	>15.0	50C	INCO (3)
Magnesium, AZ31B	W	402	2,370	–	100C	INCO (3)
Magnesium, AZ31B	S	402	2,370	11.0	S	INCO (3)
Magnesium, AZ31B	W	182	5	>40.0	95C	INCO (3)
Magnesium, AZ31B	W	366	5	>20.0	100C	INCO (3)

Continued

Table 86. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion Rate (mpy)	Corrosion Type[b]	Source[c]
Magnesium, HK31A	W	403	6,780	-	S-G[d]	NADC (7)
Magnesium, HK31A	W	197	2,340		EX-G[d]	NADC (7)
Molybdenum	W	402	2,370	0.8	C (9); U	CEL (4)
Molybdenum	S	402	2,370	0.8	C (6); U	CEL (4)
Molybdenum	W	182	5	1.4	U	CEL (4)
Molybdenum	W	364	5	1.1	U-ET	CEL (4)
Molybdenum	W	723	5	1.1	G	CEL (4)
Molybdenum	W	763	5	1.0	C (6); G	CEL (4)
Platinum	W	402	2,370	0.0	NC	CEL (4)
Platinum	S	402	2,370	0.0	NC	CEL (4)
90Pt-10Cu	W	402	2,370	0.0	NC	CEL (4)
90Pt-10Cu	S	402	2,370	0.0	NC	CEL (4)
75Pt-25Cu	W	402	2,370	0.0	NC	CEL (4)
75Pt-25Cu	S	402	2,370	0.0	NC	CEL (4)
50Pt-50Cu	W	402	2,370	–	ET	CEL (4)
50Pt-50Cu	S	402	2,370	–	ET; P	CEL (4)
25Pt-75Cu	W	402	2,370	–	ET; P	CEL (4)
25Pt-75Cu	S	402	2,370	–	ET; P	CEL (4)
Silver	W	402	2,370	0.6	U	CEL (4)
Silver	S	402	2,370	0.5	U	CEL (4)
Tantalum	W	402	2,370	0.0	NC	CEL (4)
Tantalum	S	402	2,370	0.0	NC	CEL (4)
Tantalum	W	182	5	0.0	NC	CEL (4)
Tantalum	W	364	5	0.0	NC	CEL (4)
Tantalum	W	723	5	0.0	NC	CEL (4)
Tantalum	W	763	5	0.0	NC	CEL (4)
Ta-60	W	182	5	0.0	NC	CEL (4)
Ta-60	W	364	5	0.0	NC	CEL (4)
Ta-60	W	723	5	0.0	NC	CEL (4)
Ta-60	W	763	5	0.0	NC	CEL (4)
Tin	W	123	5,640	0.5	G	INCO (3)
Tin	S	123	5,640	0.6	G	INCO (3)
Tin	W	403	6,780	1.4	P (17)	INCO (3)
Tin	S	403	6,780	1.7	SH-CR	INCO (3)
Tin	W	751	5,640	20.4	P (PR)(30)	INCO (3)
Tin	S	751	5,640	0.1	G	INCO (3)
Tin	W	1,064	5,300	< 0.1	SC-ET	INCO (3)
Tin	S	1,064	5,300	0.3	G	INCO (3)
Tin	W	197	2,340	1.8	C (2); CR (2)	INCO (3)
Tin	S	197	2,340	< 0.1	P (2)	INCO (3)
Tin	W	402	2,370	1.6	SC-P (9)	INCO (3)
Tin	S	402	2,370	0.1	C (1)	INCO (3)
Tin	W	182	5	8.3	P (PR)(30)	INCO (3)
Tin	W	366	5	2.8	C (PR)(30); P (PR)(30)	INCO (3)

Continued

Table 86. Continued.

Alloy	Environment[a]	Exposure (day)	Depth (ft)	Corrosion		Source[c]
				Rate (mpy)	Type[b]	
Tungsten	W	402	2,370	0.6	U	CEL (4)
Tungsten	S	402	2,370	0.5	U	CEL (4)
Tungsten	W	182	5	2.8	U	CEL (4)
Tungsten	W	364	5	3.2	U	CEL (4)
Tungsten	W	723	5	3.7	U	CEL (4)
Tungsten	W	763	5	4.0	U	CEL (4)
Zinc	W	123	5,640	6.7	P (13)	INCO (3)
Zinc	S	123	5,640	5.0	P (25)	INCO (3)
Zinc	W	403	6,780	5.9	C (PR)(30)	INCO (3)
Zinc	S	403	6,780	0.2	G	INCO (3)
Zinc	W	751	5,640	3.6	G	INCO (3)
Zinc	S	751	5,640	2.8	G	INCO (3)
Zinc	W	1,064	5,300	2.4	CR; E	INCO (3)
Zinc	S	1,064	5,300	0.7	G	INCO (3)
Zinc	W	197	2,340	2.3	P (2)	INCO (3)
Zinc	S	197	2,340	0.3	G	INCO (3)
Zinc	W	402	2,370	2.8	G	INCO (3)
Zinc	S	402	2,370	2.4	GASL	INCO (3)
Zinc	W	182	5	4.5	P (5)	INCO (3)
Zinc	W	366	5	2.8	P (10)	INCO (3)

[a]W = Totally exposed in seawater on sides of structure; S = Exposed in base of structure so that the lower portions of the specimens were embedded in the bottom sediments.

[b]Symbols for types of corrosion:

C	= Crevice	PR	= Perforated	GASL	= General above sediment line.
CR	= Cratering	S	= Severe		
ET	= Etched	SC	= Scattered		
EX	= Extensive	SH	= Shallow		
G	= General	U	= Uniform		
N	= Numerous	50C	= 50% corroded		
NC	= No visible corrosion	95C	= 95% corroded		
P	= Pitting	100C	= 100% corroded		

Numbers in parentheses indicate maximum depth in mils.

[c]Numbers refer to references at end of report.

[d]Thick, black, brittle crust of corrosion products.

Table 87. Changes in Mechanical Properties of Miscellaneous Alloys Due to Corrosion

Alloy	Exposure (day)	Depth (ft)	Tensile Strength		Yield Strength		Elongation		Source[a]
			Original (ksi)	% Change	Original (ksi)	% Change	Original (%)	% Change	
Molybdenum	402	2,370	14	+3	12	+9	17	-20	CEL (4)
Molybdenum[b]	402	2,370	14	+3	12	+4	17	-29	CEL (4)
Molybdenum	181	5	14	-2	12	+1	17	-14	CEL (4)
Molybdenum	364	5	14	-5	12	+2	17	-29	CEL (4)
Tantalum	402	2,370	49	-3	37	-4	49	-6	CEL (4)
Tantalum[b]	402	2,370	49	-3	37	+1	49	-5	CEL (4)
Tantalum	181	5	49	-4	37	-11	49	-5	CEL (4)
Tantalum	364	5	49	-3	37	-18	49	+66	CEL (4)
Columbium	402	2,370	114	+6	102	-3	12	-17	CEL (4)
Columbium[b]	402	2,370	114	-3	102	0	12	0	CEL (4)
Columbium	181	5	114	-3	102	-2	12	+2	CEL (4)
Columbium	364	5	114	-5	102	-20	12	+33	CEL (4)

[a]Numbers refer to references at end of report.

[b]Exposed in bottom sediments.

SECTION 9

WIRE ROPES

Wire ropes of many different chemical compositions, with different types of coatings, of different sizes, and of different types of construction were exposed in seawater at depth to determine their corrosion behavior. Some were stressed in tension to determine their susceptibility to stress corrosion or whether stress increased their rates of corrosion.

The chemical compositions of the ropes are given in Table 88, and their corrosion behavior in Table 89.

There was no visible corrosion on rope numbers 15, 18, 19, 20, 21, 22, 41 (751 days, 6,000 feet), 48, 49, 50, 51, 52, and 53. Rope number 15 was Type 316 stainless steel modified by adding silicon and nitrogen and was exposed for 189 days at the 6,000-foot depth. Wire rope number 41, conventional Type 316, was uncorroded after 751 days of exposure at the 6,000-foot depth, but was rusted with some internal wires broken and crevice corrosion after 1,064 days of exposure; its breaking strength was decreased by 41% after 1,064 days of exposure at the 6,000-foot depth. Because the conventional Type 316 stainless steel was not corroded until between 751 and 1,064 days of exposure, it cannot be stated that the addition of silicon and nitrogen to the Type 316 stainless steel improved its corrosion resistance.

Rope numbers 18, 19, 20, and 21 were nickel base alloys. Rope numbers 20 and 21 were also uncorroded when lying on or in the bottom sediment.

Rope number 22 was a cobalt base alloy which was also uncorroded when lying on or in the bottom sediment. It, also, was not susceptible to stress corrosion in either the seawater or the bottom sediment when stressed to 40% of its breaking strength.

Rope numbers 48, 49, 50, 51, 52, and 53 were 6Al-4V-Ti ropes and wires. The ropes and wires themselves were not corroded, but the Type 304 stainless steel fittings and steel tie wires were severely corroded galvanically.

All the other wire ropes, coated or uncoated, were corroded to varying degrees of severity, the most severe being the parting of the wires.

Bare steel wires 1, 2, 3, 35, and 36, as expected, were completely covered with rust. There was no loss of strength after periods of exposure of as long as 1,064 days. These ropes had been lubricated during fabrication; the lubricant on the outer surfaces of the ropes had disappeared, but not on the internal surfaces during exposure. One rope, No. 2, was degreased prior to exposure. as a result, it was more severely corroded than the others on the outside surfaces, and there was light rust on many of the internal wires. One rope, No. 3, was degreased, then wrapped with 10-mil-thick polyethylene tape prior to exposure. There was heavy rust underneath the tape for a distance of about 3 feet from each end and there was light rust on about 75% of the internal wires. Wires 35 and 36 had been stressed in tension to 20% of their respective breaking strengths prior to exposure. These two ropes were covered with rust with no rust on the internal wires, did not fail by stress corrosion, and had no decrease in their breaking strengths.

The galvanized (zinc-coated) ropes were numbers 4, 5, 6, 23, 24, 25, 26, 27, 28, 37, and 38. The zinc coatings protected the steel wires, but there was no good correlation between the weight or thickness of coating and the duration of protection. In general, except for the electrogalvanized coating, the heavier the coating the longer the period of time before rust appeared on the ropes. The breaking strengths of the ropes were not impaired by exposures for as long as 1,064 days of exposure. Also, rope numbers 37 and 38 were not susceptible to stress corrosion when stressed to 20% of their respective breaking strengths.

Rope numbers 7, 8, 9, and 40, in addition to being galvanized, were also jacketed with plastic coatings. In all cases, seawater penetrated along the interfaces between the ropes and the jackets. There was some light rust on the strands of rope number 40 underneath the poly(vinyl chloride) jacket after 751 days of exposure. The polyurethane (rope number 7) and polyethylene (rope numbers 8 and 9) jackets protected the galvanized ropes to a considerable extent. The jackets were not punctured or broken, but seawater had penetrated to the metal ropes through the end terminations. That water had penetrated to the interface between the jackets and the ropes was proven by puncturing the jackets, at which time seawater spurted out under considerable pressure. When a terminal was removed from one end of each specimen, the zinc coatings were gone from the portions of the ropes which had been inside the terminals and the wires of the strands were rusted. The polyethylene jacket on one rope (number 9) had been punctured in many places prior to exposure. After exposure these holes were filled with white corrosion products; there was pressure underneath the jacket; and there was no rust on the wires except inside the terminals.

Rope numbers 39, 43, 44, and 45 were aluminized (coated with a layer of aluminum). Aluminum coatings afforded considerable protection to steel ropes in the same manner as did zinc coatings. A 0.38-oz/sq ft of aluminum coating (1.4 mils thick) afforded protection to steel rope for about the same period of time as did an 0.83-oz/sq ft of zinc coating (1.4 mils thick). In deep-ocean environments, equal thicknesses of coatings of zinc and aluminum protected steel ropes for about the same periods of time, but on a weight basis zinc was about twice as heavy as aluminum. There was no decrease in breaking strength caused by corrosion. Also, rope number 39 was not susceptible to stress corrosion when stressed at 20% of its breaking strength.

Rope numbers 10, 11, 12, 13, 14, 15, 16, 17, 29, 30, 31, 32, 33, 34, 41, and 42 were stainless steels of different chemical compositions. The 0.1875-inch-diameter Type 304 stainless steel ropes (10, 11, 12, 13, 29, 30, and 31), stress relieved and not stress relieved, were corroded by crevice, pitting, and tunnel corrosion; and many of the wires had parted because of corrosion, particularly internal wires. There were only rust spots on the larger diameter, 0.250-through-0.375-inch, Type 304 ropes (32, 33, and 34) for equivalent periods of exposure. The addition of vanadium and nitrogen (rope number 16) to the Type 304 composition did not improve the corrosion resistance of the Type 304 stainless steel. The addition of copper (rope number 14) to the Type 316 stainless steel composition impaired its corrosion resistance, while the addition of silicon and nitrogen (rope number 15) did not appear to have any influence. The conventional Type 316 stainless steel (rope number 41) was uncorroded after 751 days of exposure, but after 1,064 days there were many internal wires broken as a result of attack by crevice corrosion. The breaking strengths of most of the stainless steel ropes were impaired by exposure in seawater at depth. Rope numbers 41 and 42 were not susceptible to stress corrosion when stressed at 20% of their respective breaking strengths.

Two Type 304 stainless steel ropes (numbers 46 and 47) were clad with 90% copper-10% nickel alloy. Rope number 46, which had a clad layer 0.7 inch thick, had a green color after 402 days of exposure, indicating that the Cu-Ni clad layer had not been completely sacrificed. However, rope number 47, which had a clad layer 0.3 mil thick, was covered with a light film of rust, indicating that it had been completely sacrificed during the same period of time. In both cases the internal wires of the ropes were uncorroded.

Table 88. Chemical Composition of Wire Ropes

Rope	C	Mn	P	S	Si	Ni	Cr	Mo	Cu	Co	Fe[a]	Other
Fe-Cr-Ni-Mo-Cu	0.065	1.55	0.010	0.013	1.39	13.90	18.64	2.44	1.95	—	R	0.060 N, <0.01 Zr, <0.02 V
Fe-Cr-Ni-Mo-Si-N	0.072	1.60	0.013	0.015	2.28	13.80	18.70	2.47	< 0.02	—	R	0.17 N, <0.01 Zr, <0.02 V
Fe-Cr-Ni-V-N	0.070	1.35	0.012	0.014	0.98	13.70	19.56	< 0.01	< 0.02	—	R	0.15 N, <0.01 Zr, 3.50 V
Fe-Cr-Ni-Si	0.063	1.51	0.005	0.008	1.92	17.82	17.82	0.02	0.03	—	R	—
Ni-Mo-Cr-C	0.014	0.45	0.010	0.008	0.53	60.2	15.9	15.0	—	—	3.56	0.080 V, 3.14 W
Ni-Co-Cr-Mo	—	—	—	—	—	35.0	20.0	10.0	—	35.0	—	—
Ni-Cr-Mo 103	0.02	—	—	—	—	67.0	18.0	14.0	—	—	—	0.50 Cb
Ni-Cr-Mo 625	0.05	—	—	0.007	0.30	61.0	22.0	9.0	0.10	—	3.0	Cb + 4.0 Ta
Co-Cr-Ni-Fe-Mo	0.050	1.96	—	—	0.74	14.96	19.84	7.14	—	40.46	14.60	0.058 Al, 0.07 Be, 0.058 Zr, 0.011 Ca
Cr-Mn-N	0.07	14.3	0.021	0.003	0.67	0.27	18.4	—	—	—	R	0.48 N
AISI type 304[b]	0.08	—	—	—	—	10.0	19.0	—	—	—	R	—
AISI type 316[b]	0.08	—	—	—	—	12.0	17.0	2.5	—	—	R	—
90-10 Clad 304[b]												
304 Core	0.08	—	—	—	—	10.0	19.0	—	—	—	R	—
90-10 Clad	—	—	—	—	—	10.0	—	—	90.0	—	—	—
Aircraft cable[c]												
Plow steel[d]												
Improved plow steel[e]												
Monitor steel[f]												
Monitor AA steel[g]												

[a]R = remainder.

[b]Nominal chemical composition.

[c]No chemical composition requirements; but strength requirements very high, especially for processed carbon steel wire.

[d]No chemical composition requirements; only mechanical strength requirements.

[e]No chemical composition requirements; mechanical strength requirements 15% higher than those for plow steel.

[f]Same as plow steel.

[g]Same as improved plow steel.

Table 89. Corrosion of Wire Ropes

Rope No.	Alloy[a]	Coating	Diameter (in.)	Construction	Stress on Rope (lb)	Exposure (day)	Depth (ft)	Breaking Load Original (lb)	Breaking Load Final (lb)	Breaking Load % Change	Remarks
1	Plow steel	lubricated	0.875	7 x 19	0	123	6,000	48,200	48,200	0	Rust on crowns of outside wires; lubricant still in grooves; inside: wires bright; tensile fracture.
1	Plow steel	lubricated	0 875	7 x 19	0	751	6,000	48,200	45,800	-5	Outside: 100% rust; inside: wires bright; tensile fracture.
2	Plow steel	degreased	0.875	7 x 19	0	123	6,000	48,200	48,200	0	Outside: 100% rust; inside: wires light rust, few bright spots; tensile and torsion fractures.
2	Plow steel	degreased	0.875	7 x 19	0	751	6,000	48,200	49,300	+2	Outside: 100% rust; inside: wires light rust, few bright spots; tensile fracture.
3	Plow steel	degreased; covered with 10-mil polyethylene tape	0.875	7 x 19	0	123	6,000	48,200	48,900	+2	Rust underneath tape for about 3 feet from ends; inside: 50% light rust, 50% bright; tensile and torsion fractures.
3	Plow steel	degreased; covered with 10-mil polyethylene tape	0.875	7 x 19	0	751	6,000	48,200	48,200	0	Heavy rust at edges and underneath tape for about 3 feet from ends, inside: 75% light rust, 25% bright; tensile fracture.
4	Improved plow steel	Zn 0.50 oz/ft^2	0 250	3 x 19	0	189	6,000	-	–	–	Outside: light, uniform rust, heavy in some grooves.
5	Improved plow steel	Zn 0.70 oz/ft^2	0.500	3 x 19	0	189	6,000	-			Outside: yellow with few areas of heavy rust in grooves.
6	Improved plow steel	Zn 0.90 oz/ft^2	0 500	3 x 7	0	189	6,000	-	–	–	Outside: grey-yellow, few areas of white corrosion products, few areas of heavy yellow corrosion products in grooves.
7	Improved plow steel	Zn 0.70 oz/ft^2, polyurethane jacket	0.500	3 x 19	0	189	6,000		-	-	No breaks in coating; white corrosion products on ends of terminals; terminations not watertight.
8	Improved plow steel	Zn 0.70 oz/ft^2, polyethylene jacket	0.500	3 x 19	0	189	6,000		–	-	No breaks in coating; white corrosion products on ends of terminals; terminations not watertight.
9	Improved plow steel	Zn 0.70 oz/ft^2, punctured polyethylene jacket	0.500	3 x 19	0	189	6,000	-	-	–	No rust at punctures in jacket; no breaks in coating; white corrosion products at ends of terminals; terminations not watertight.
10	AISI Type 304	not stress relieved	0.1875	3 x 19	0	189	6,000	–	–	–	Dull grey with light rust stains; 12-in. length near center of wire covered with heavy red rust; some broken wires; when cleaned, many broken wires, tunnel, pitting, and crevice corrosion.
11	AISI Type 304	stress relieved	0.1875	3 x 19	0	189	6,000	–	–	–	Dull grey; some light rust stains; heavy rust at edges of silicone potting compound; broken wires at edge of silicone compound under heavy rust at one end (crevice corrosion); when cleaned, numerous broken wires, internal tunnel, pitting, and crevice corrosion.
12	AISI Type 304	not stress relieved	0.1875	3 x 7	0	189	6,000	–	–	–	Dull grey; light rust and some heavy rust in some areas; crevice corrosion; when cleaned, broken wires, tunnel, pitting, and crevice corrosion.

Continued

Table 89. Continued.

Rope No.	Alloy[a]	Coating	Diameter (in.)	Construction	Stress on Rope (lb)	Exposure (day)	Depth (ft)	Breaking Load Original (lb)	Breaking Load Final (lb)	Breaking Load % Change	Remarks
13	AISI Type 304	stress relieved	0.1875	3 x 7	0	189	6,000	–	–	–	Dull grey; light rust stains; few pits on crowns of outside wires; when cleaned, crevice, pitting, and tunnel corrosion.
14	Fe-Cr-Ni-Mo-Cu	bare	0.125	3 x 7	0	189	6,000	–	–	–	Dull grey with mottled light yellow stains; when cleaned, incipient crevice corrosion.
15	Fe-Cr-Ni-Mo-Si-N	bare	0.125	1 x 7	0	189	6,000	–	–	–	No visible corrosion; metallic sheen still present.
16	Fe-Cr-Ni-V-N	bare	0.125	1 x 7	0	189	6,000	–	–	–	Failed by tunnel and crevice corrosion underneath silicone potting compound; only end loops recovered.
17	Fe-Cr-Ni-Si	bare	0.125	1 x 7	0	189	6,000	–	–	–	Grey, no visible corrosion; when cleaned, many areas of slight crevice corrosion and shallow pitting.
18	Ni-Co-Cr-Mo	bare	0.0625	1 x 7	0	189	6,000	–	–	–	No visible corrosion; original metallic sheen intact.
19	Ni-Mo-Cr C	bare	0.0625	1 x 7	0	189	6,000	–	–	–	No visible corrosion; original metallic sheen intact.
20	Ni-Cr-Mo 625	bare	0.250	7 x 19	0	189	6,000	7,400	–	–	No visible corrosion; original metallic sheen intact.
20	Ni-Cr-Mo 625[b]	bare	0.250	7 x 19	0	189	6,000	7,400	–	–	No visible corrosion; original metallic sheen intact.
21	Ni-Cr-Mo 103	bare	0.250	7 x 19	0	189	6,000	7,000	–	–	No visible corrosion; original metallic sheen intact.
21	Ni-Cr-Mo 103[b]	bare	0.250	7 x 19	0	189	6,000	7,000	–	–	No visible corrosion; original metallic sheen intact.
22	Co-Cr-Ni-Fe-Mo	bare	0.1875	3 x 19	0	189	6,000	4,000	–	–	Original blue film gone; no visible corrosion.
22	Co-Cr-Ni-Fe-Mo	bare	0.1875	3 x 19	1,600	189	6,000	4,000	–	–	No wire failures, original blue film gone; no visible corrosion.
22	Co-Cr-Ni-Fe-Mo[b]	bare	0.1875	3 x 19	0	189	6,000	4,000	–	–	Original blue film gone; no visible corrosion.
22	Co-Cr-Ni-Fe-Mo[b]	bare	0.1875	3 x 19	1,600	189	6,000	4,000	–	–	No wire failures; original blue film gone; no visible corrosion.
23	Aircraft cord	Zn 0.40 oz/ft^2	0.0938	7 x 7	0	403	6,000	1,100	1,100	0	Dark grey to black; tensile fracture.
23	Aircraft cord	Zn 0.40 oz/ft^2	0.0938	7 x 7	0	197	2,500	1,100	1,000	-9	Outside. 100% rust; inside: grey, tensile fracture.
24	Aircraft cable	Zn 0.40 oz/ft^2	0.125	7 x 19	0	403	6,000	2,000	1,000	-50	Dark grey to black; inside. grey; tensile fracture.
24	Aircraft cable	Zn 0.40 oz/ft^2	0.125	7 x 19	0	197	2,500	2,000	1,800	-10	Outside: 100% rust; inside: grey; tensile and torsion fractures.
25	Aircraft cable	Zn 0.50 oz/ft^2	0.1875	7 x 19	0	403	6,000	3,500	4,000	+14	Outside. dark grey to black; inside: grey, tensile and torsion fractures.
25	Aircraft cable	Zn 0.50 oz/ft^2	0.1875	7 x 19	0	197	2,500	3,500	3,700	+6	Outside. dark grey; inside: grey; tensile and torsion fractures.
26	Wire rope	Zn 0.50 oz/ft^2	0.1875	1 x 7	0	403	6,000	2,600	2,600	0	Outside: 90% rust, inside: grey; tensile fracture.
26	Wire rope	Zn 0.50 oz/ft^2	0.1875	1 x 7	0	197	2,500	2,600	2,500	-4	Outside: medium grey, few rust spots; inside: grey; tensile fracture.

Continued

Table 89. Continued.

Rope No.	Alloy[a]	Coating	Diameter (in.)	Construction	Stress on Rope (lb)	Exposure (day)	Depth (ft)	Breaking Load Original (lb)	Breaking Load Final (lb)	Breaking Load % Change	Remarks
27	Wire rope	Zn 0.85 oz/ft^2	0.250	1 x 7	0	403	6,000	5,900	4,600	-22	Outside: 100% yellow; inside: grey; tensile fracture.
27	Wire rope	Zn 0.85 oz/ft^2	0.250	1 x 7	0	197	2,500	5,900	5,300	-10	Outside: medium grey, few rust spots; inside: grey; tensile fracture.
28	Aircraft cable	Zn 0.60 oz/ft^2	0.250	7 x 19	0	403	6,000	6,100	5,900	-2	Outside: dark grey to black; inside: grey; tensile and torsion fractures.
28	Aircraft cable	Zn 0.60 oz/ft^2	0.250	7 x 19	0	197	2,500	6,100	6,200	+2	Outside: dark grey to black; inside: grey; tensile fracture.
29	Aircraft cord	bare, Type 304	0.0938	7 x 7	0	403	6,000	800	100	-88	Internal strands corroded; tunnel, crevice, and pitting; many wires parted by corrosion.
29	Aircraft cord	bare, Type 304	0.0938	7 x 7	0	197	2,500	800	800	0	Outside: few rust spots; inside: bright; tensile fracture.
30	Aircraft cable	bare, Type 304	0.125	7 x 19	0	403	6,000	1,600	200	-88	Outside: few rust stains; inside: broken wires, crevice and pitting corrosion.
30	Aircraft cable	bare, Type 304	0.125	7 x 19	0	197	2,500	1,600	1,800	+13	Outside: original metallic lustre; inside: bright; tensile fracture.
31	Aircraft cable	bare, Type 304	0.1875	7 x 19	0	403	6,000	2,700	100	-96	Outside: many rust stains and broken wires, pitting, tunnel and crevice corrosion; inside: many broken wires, pitting, tunnel, and crevice corrosion.
31	Aircraft cable	bare, Type 304	0.1875	7 x 19	0	197	2,500	2,700	2,800	+4	Outside: few rust spots; inside: bright; tensile fracture.
32	Aircraft cable	bare, Type 304	0.250	7 x 19	0	403	6,000	5,100	5,000	-2	Outside. few yellow stains; inside: bright; tensile fracture.
32	Aircraft cable	bare, Type 304	0.250	7 x 19	0	197	2,500	5,100	5,100	0	Outside. original metallic sheen; inside: bright; tensile and torsion fractures.
33	Aircraft cable	bare, Type 304	0.3125	7 x 19	0	403	6,000	7,100	7,700	+8	Outside: few rust stains, inside: bright; tensile and torsion fractures.
33	Aircraft cable	bare, Type 304	0.3125	7 x 19	0	197	2,500	7,100	7,000	-1	Outside: original metallic lustre; inside: bright; tensile fracture.
34	Aircraft cable	bare, Type 304	0.375	7 x 19	0	403	6,000	11,900	11,700	-2	Outside: few rust stains, inside: bright; tensile and torsion fractures.
34	Aircraft cable	bare, Type 304	0.375	7 x 19	0	197	2,500	11,900	11,600	-3	Outside: few rust stains; inside: bright; tensile fracture.
35	Plow steel	lubricated	0.325	1 x 19	2,100	751	6,000	10,700	10,700	0	No stress failure, outside: 100% rust; inside: bright; tensile fracture.
35	Plow steel	lubricated	0.325	1 x 19	2,100	1,064	6,000	10,700	11,500	+7	No stress failure, outside: 100% rust; inside: bright; tensile fracture.
36	Improved plow steel	lubricated	0.326	1 x 19	2,900	751	6,000	14,300	14,900	+4	No stress failure, outside: 100% rust; inside: bright; tensile fracture.

Continued

Table 89. Continued.

Rope No.	Alloy[a]	Coating	Diameter (in.)	Construction	Stress on Rope (lb)	Exposure (day)	Depth (ft)	Breaking Load Original (lb)	Breaking Load Final (lb)	Breaking Load % Change	Remarks
36	Improved plow steel	lubricated	0.326	1 x 19	2,900	1,064	6,000	14,300	15,300	+7	No stress failure; outside: 100% rust; inside: bright; tensile failure.
37	Plow steel	Zn 0.83 oz/ft^2	0.340	1 x 19	2,100	751	6,000	10,400	10,900	+5	No stress failure; outside: grey with 5% scattered rust; inside. grey; tensile fracture.
37	Plow steel	Zn 0.83 oz/ft^2	0.340	1 x 19	2,100	1,064	6,000	10,400	8,600	-17	No stress failure, outside: 20% rust, 80% yellow; inside: grey, tensile fracture.
38	Plow steel	Zn 1.50 oz/ft^2, electrogalvanized	0.335	1 x 19	2,200	751	6,000	10,900	11,100	+2	No stress failure; outside: 50% rust, 50% grey; inside grey; tensile fracture.
38	Plow steel	Zn 1.50 oz/ft^2, electrogalvanized	0.335	1 x 19	2,200	1,064	6,000	10,900	11,600	+6	No stress failure; outside: 95% rust; inside: grey; tensile fracture.
39	Plow steel	Al 0.38 oz/ft^2	0.335	1 x 7	1,400	751	6,000	6,900	7,000	+1	No stress failure; outside. white corrosion products with 10% rust stains; inside: grey; tensile fracture.
39	Plow steel	Al 0.38 oz/ft^2	0.335	1 x 7	1,400	1,064	6,000	6,900	6,500	-6	No stress failure; outside. white corrosion products plus 50% rust; inside: grey and light rust; tensile fracture.
40	Plow steel	Zn 0.17 oz/ft^2, polyvinyl chloride jacket	0.195	7 x 7	250	751	6,000	1,300	1,200	-8	No stress failure; PVC, dull; some light rust on strands underneath PVC; tensile fracture.
40	Plow steel	Zn 0.17 oz/ft^2, polyvinyl chloride jacket	0.195	7 x 7	250	1,064	6,000	1,300	1,100	-15	No stress failure, PVC, dull; some light rust on strands underneath PVC; tensile and torsion fractures.
41	Aircraft cable	bare, Type 316, lubricated	0.135	7 x 7	350	751	6,000	1,700	1,400	-18	No stress failure; outside: original metallic lustre, inside: bright; tensile fracture.
41	Aircraft cable	bare, Type 316, lubricated	0.135	7 x 7	350	1,064	6,000	1,700	1,000	-41	No stress failure; outside: 50% rust, crevice corrosion, inside: rusted wires, some broken, crevice corrosion, tensile and brittle fractures
42	Aircraft cable	bare, 18Cr-14Mn-0.5N	0.395	7 x 19	2,500	751	6,000	12,400	11,400	-8	No stress failures, outside. few rust spots, inside: bright; torsion fracture.
42	Aircraft cable	bare, 18Cr-14Mn-0.5N	0.395	7 x 19	2,500	1,064	6,000	12,400	12,500	+1	No stress failure, outside considerable rust and broken wires, inside: some broken wires in all strands; torsion fracture.
43	Improved plow steel	Al 0.11 oz/ft^2	0.1875	7 x 7	0	402	2,500	3,900	3,500	-10	Outside: white corrosion products with light rust stains.
44	Improved plow steel	Al 0.19 oz/ft^2	0.250	1 x 19	0	402	2,500	8,800	7,800	-11	Outside: mottled white and grey
45	Improved plow steel	Al 0.19 oz/ft^2	0.3125	1 x 19	0	402	2,500	14,000	13,000	-7	Outside: grey with some white corrosion products.
46	Type 304	90Cu-10Ni, 0.0007 in., 0.50 oz/ft^2	0.1875	7 x 7	0	402	2,500	3,900			Outside. green.

Continued

Table 89. Continued.

Rope No.	Alloy[a]	Coating	Diameter (in.)	Construction	Stress on Rope (lb)	Exposure (day)	Depth (ft)	Breaking Load Original (lb)	Final (lb)	% Change	Remarks
47	Type 304	90Cu-10Ni, 0.0003 in., 0.25 oz/ft^2	0.280	37 x 7	0	402	2,500	–	–		Outside: light film rust; inside: bright, uncorroded.
48	6Al-4V-Ti	bare, Type 304 fittings	0 250	6 x 19	0	402	2,500	–	–		Fittings rusted, crevice and galvanic corrosion, cable, no corrosion
49	6Al-4V-Ti	bare	0.0625	1 x 19	0	402	2,500		–		No corrosion except one steel wire which had become introduced during fabrication.
50	6Al-4V-Ti	bare, steel fitting, steel tie wire	0.0625	6 x 19	0	402	2,500		–		Steel fitting and steel tie wire corroded galvanically, cable, no corrosion.
51	6Al-4V-Ti	bare	0 063	–	0	402	2,500	–			No corrosion
52	6Al-4V-Ti	bare	0 045	–	0	402	2,500	–			No corrosion.
53	6Al-4V-Ti	bare	0 020		0	402	2,500	–		–	No corrosion.

[a]Immersed in seawater unless otherwise specified.

[b]Immersed in bottom sediment.

SECTION 10

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